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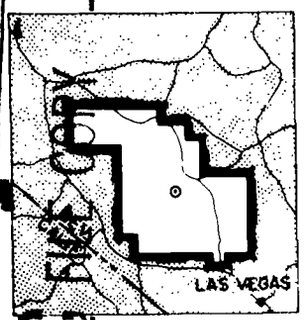

NEVADA TEST SITE
MAY-OCTOBER 1957

PROJECT 4.1

EFFECTS OF NUCLEAR DETONATIONS ON A LARGE BIOLOGICAL SPECIMEN (SWINE)

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OPERATION PLUMBBOB—PROJECT 4.1

EFFECTS OF NUCLEAR DETONATIONS ON A LARGE BIOLOGICAL SPECIMEN (SWINE)

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FOREWORD

This report presents the final results of one of the 46 projects comprising the military-effect programs of Operation Plumbbob, which included 24 test detonations at the Nevada Test Site in 1957.

For overall Plumbbob military-effects information, the reader is referred to the "Summary Report of the Director, DOD Test Group (Programs 1–9)," ITR–1445, which includes: (1) a description of each detonation, including yield, zero-point location and environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; and (4) a listing of project reports for the military-effect programs.

ABSTRACT

The data presented in this report results from investigation of the effect of nuclear devices on a large biological specimen (swine) in the following fields: injuries caused by the nuclear device, wounds produced by glass missiles as the wounding agent, and radiation studies with exposure to both gamma rays and neutrons.

The pig was chosen as the biological target because this animal approximated the human in cross section (for the radiation study) and had been the subject of previous study during Operation Greenhouse. Furthermore, considerable burn research has been done on the pig. Twelve hundred pigs were used in this medical experiment during Shots Franklin, Wilson, and Priscilla at the Nevada Test Site.

The data obtained is extrapolated, wherever possible, to humans.

Experimental design and the animal studied have been shown to be adequate for this study.

The median lethal dose of nuclear device radiation was shown to be 486 ± 10 rep of gamma rays and neutrons. The radiation syndrome and median survival times were similar to those in previous animal studies.

Wounds and burns in combination with nuclear radiation have been studied at all dose levels. Combined trauma and whole-body radiation results in earlier death and an increase in total mortality.

The living specimen within the radius of the precursor, and in the open, will experience near inevitable mortality from dismemberment or displacement. Foxholes at the same radius protect against secondary blast effects and line-of-sight thermal but not necessarily against ionizing radiation. Battlefield debris outside the precursor region does not produce significant wounds.

Analysis of the fate of a living specimen (human) in various environments was shown to be done best by exposing a test animal along with test gages or devices.

In specimens exposed to the combined injuries from a nuclear detonation, the most frequent bacteriological invaders are Staphylococcus albus, Beta-hemolytic Streptococcus and Pasteurella multocida—organisms originating from sites other than the gastrointestinal tract.

Spleen bone-marrow homogenate was ineffective in reducing the mortality from ionizing radiation.

A new procedure for total leukocyte counts is presented as a method of screening radiation casualties.

Operational concepts affecting the medical evaluation of casualties and the resultant therapy are presented.

PREFACE

This project was carried out in cooperation with several other agencies at the Nevada Test Site (NTS). Specifically, the dosimetry and a portion of the logistical effort of the radiobiology portion of this experiment were carried out as a joint participation with the Civil Effects Test Group (CETG) at the invitation of its director, Robert L. Corsbie. These efforts were under Projects 4.1.3 (DOD subproject to 4.1) and 39.7a (CETG). Payne S. Harris, M.D., Los Alamos Scientific Laboratory, was responsible for its experimental design and the coordination with other projects in Program 39 (CETG). Dosimetry for all of this experiment was done by Program 39, except as noted in the report.

The missile study (Subproject 4.1.4) was done in cooperation with Clayton S. White, M.D., Director, Lovelace Foundation for Medical Education and Research, and Director of Program 33 (CETG). This portion of the experiment depended entirely upon the analysis of the experiments performed by the Lovelace Foundation during Operation Teapot, and of the detailed shock-tube studies done at Aberdeen Proving Ground by Captain Harry A. Claypool, MC, U.S. Army, of this project (Appendix B).

The organization of this Biomedical Task Force Detachment was directed by the Surgeon General of the Army, Major General Silas B. Hays, to be carried out at the Walter Reed Army Institute of Research (WRAIR). Project personnel were derived from the Medical Services of the Army, Air Force, and Navy on a temporary-duty basis for the execution of the experiment at NTS. Personnel involved at NTS totaled 192 with the following breakdown: 59 officers (31 MC, 11 VC, 8 ANC, 1 DC, and 8 MSC), 13 civilians, and 120 enlisted personnel.

Acknowledgment is willingly made of the extensive scientific and administrative support given this project by WRAIR and also the superb support by Major General William E. Shambora, M.C., Commanding General, Brooke Army Medical Center (BAMC). The enlisted personnel from this installation were from the 67th Medical Group, BAMC.

All personnel in this project were assigned on an additional-duty basis, except for those in personnel and supply—Captain Richard W. Levardsen, MSC, Captain Paul S. Marshall, MSC, and Captain Ethelyn Hughes, ANC. The foresight and planning by these individuals was a major reason for the successful operation of the project at NTS. Details of the organization, planning, personnel, and activities of this project are on file in the following locations: Office of the Special Assistant for Nuclear Energy, Office of the Surgeon General, Department of the Army, Washington, D.C.; Division of Surgery, WRAIR, Walter Reed Army Medical Center, Washington, D.C.

For overall project planning, the basic physics and experimental design were done by Captain Harry A. Claypool. The professional medical program was planned and executed under Lieutenant Colonel William H. Moncrief, Jr., MC, USA.

In this report, Chapter 2 was prepared by Major Kent T. Woodward, MC, and Major James N. Shively, VC; Chapter 3, Lieutenant Colonel William H. Moncrief, Jr., MC; Chapter 4, Lieutenant Colonel Hinton J. Baker, MC; Chapter 5, Colonel William H. Crosby, MC, and Captain Harry W. Daniell, MC; Chapter 6, Colonel Carl F. Tessner, MC, and Captain Alexander Horava, MC; Chapter 7, Lieutenant Colonel Joseph D. Goldstein, MC; Chapters 8, 9, and 10, and Appendixes A and B, Captain Harry A. Claypool, MC.

An additional comment is pertinent. Radiation dosages in this report are given in roentgen equivalent physical (rep). The preferred dosage unit is the rad, which signifies an energy absorption of 100 ergs/gram of whatever medium is under discussion. This unit is not used in the report, because the neutron and gamma dosimeters had been calibrated by the dosimetrists (Harris, Sigoloff, Hurst, and Ritchie) in rep prior to the experiment. Suitable conversion factors can be applied by those desiring this data in rads.

CONTENTS

TABLES

FIGURES

Chapter 1

INTRODUCTION

The general objective was to investigate by medical experiment the effects of nuclear devices on a large biological specimen in an attempt to define more specifically the effects on humans.

1.1 SELECTION OF SPECIMEN

It is often difficult to extrapolate from a physical measurement to a predicted biological response without considerable experience in correlation of these responses. Some effects of nuclear weapons have been observed in humans since 1945; but with the development of tactical formations and civil-defense planning involving nuclear weapons, there is a requirement for further analysis of the weapon effects individually and in combination.

In the absence of experimentation on man, the investigation must utilize animals approximating man in physiology and response to trauma. Of the large subprimate animals, there is more familiarity with the dog than any other. However, in order to perform this field experiment, some 1,000 animals were required; the use of so many dogs would have presented near-impossible logistic and publicity problems.

The next animal investigated was the goat. It has been studied at the Chemical Warfare Laboratories and at the Army Medical Service School, Brooke Army Medical Center (BAMC), as an animal for analysis of wounds produced by high-velocity missiles. It was found, however, that the goat is fragile when shorn of its coat. Further, the exposed skin is unlike that of the human. An additional disadvantage of this animal is that about four-fifths of its surface area, in its side-on silhouette, overlies the gastrointestinal tract, which includes four stomachs.

The calf was also considered, but it was rejected because of the logistics of providing 1,000 animals on a given date and because of the serious disease problems presented by this animal in the field.

The next animal considered was the pig. Its advantage was that considerable burn research had been done with the pig, both in the laboratory and during Operation Greenhouse. The pig, notably a hardy animal, withstands trauma that would be lethal to many animals. Before this animal could be used in the field, considerable surgical and physiological investigation was done at Water Reed Army Institute of Research (WRAIR). This is reviewed in Chapters 3 and 4.

1.2 PROCUREMENT OF SWINE

The gestation period for swine is 112 to 120 days. The average weight and age is 40 pounds at 60 days, 65 pounds at 90 days, and 100 pounds at 120 days. Thus, to have 60-to-70-pound test animals, a minimum of 210 days is required. There must be added to

this the 30 days required by the breeder to arrange for delivery of some 1,500 animals (from which the 1,200 test subjects are chosen). Note that in the interval between 90 and 120 days of life, the animal will weigh about 100 pounds, a weight that makes handling in the field exceedingly difficult.

Thus, for a readiness date of 1 May, the breeding must be accomplished by about 1 October of the previous year. Further, a 30-day postponement results in an inevitable increase in size of the animal, thereby complicating the experimental procedures.

The pigs used in this experiment were obtained from a breeder in Trimble, Missouri, and were a Hampshire-Landrace strain with occasional swine having Duroc coloration. Shipment to the Nevada Test Site (NTS) was by double-decked truck and required 2 days en route. The animals were received in good condition. All animals were grain fed. They had not received antibiotics in their feed except at weaning (third week). They were free from disease and external parasites and were immunized against hog cholera and swine erysipelas.

1.3 HANDLING OF SWINE AT NTS

The animal-holding facility at NTS was on the south rim of the Frenchman Flat area between the main highway and the Frenchman Flat access road near Pump House 4 (Figures 1.1, 1.2, and 1.3). A field hospital, for the treatment of nuclear casualties, was located adjacent to the facility. This area was chosen because of accessibility to a plentiful water supply, excellent natural drainage, good access roads, and isolation from Camp Mercury proper.

The criteria for design of this field hospital and holding facility were austere but adequate. Concrete floors were laid only where absolutely necessary, e.g., hospital, autopsy facility, central materiel, laboratory, and animal pens.

The swine were housed twenty per pen prior to exposure. Food consumption averaged 2.5 pounds per day (basically a 14-percent protein diet), and water was always available.

The normal late spring weather at NTS has moderate temperatures with humidity of less than 10 percent. Actual weather subsequent to 7 May 1957, the date of establishment of the colony at NTS, included temperatures below 60 degrees F, rain, fog, and even icing on one occasion. Only by a supreme effort on the part of the group from the Veterinary Division, WRAIR, was a respiratory epidemic prevented. If such an epidemic or uncontrolled porcine disease had occurred, the experimental program would have been curtailed or even eliminated.

Soon after arrival of the animals at NTS, Shot Priscilla was postponed until 15 June. Subproject 4.1.3 (described in Section 1.4) was scheduled for Shot Franklin on 15 May. Internal dosimeters were surgically placed prior to 10 May (Chapter 2). Repeated delays in Shot Franklin and postponement of the detonation as little as 1 hour prior to scheduled shot time resulted in considerable animal handling and travel. Shot Franklin occurred 2 June. Because of device malfunction, no significant exposure of the test animals to nuclear radiation resulted. This experiment was rescheduled for Shot Wilson, due on 8 June. After rescheduling and postponements, this detonation occurred 18 June.

The animals were transported by truck to the exposure area. Up to 40 pigs were transported in the bed of a standard 6 × 6 truck. Prior to Shot Wilson, the entire group of animals was transported to and from the exposure site on five occasions because of shot cancellations—a total distance of 250 miles.

The preceding comments are submitted for the benefit of subsequent experimenters in biomedical tests, and also for those administrative planners who may be involved. The

latter do not always appreciate the significance and difficulties of dealing with the complicated living specimen that requires infinitely more planning and logistical support than the inanimate device or object at nuclear tests.

1.4 INTERRELATIONSHIP OF SUBPROJECTS

It was originally planned that the project would investigate the methods of management of multiple casualties derived from a nuclear device. Extensive pretest studies indicated, however, that the pig was not a suitable specimen for differentiation of surgical methods. On the basis of the extensive pretest analysis, it was felt that the objectives of this project could profitably be:

1. Subproject 4.1.1. To obtain injuries in the pig and attempt surgical correction for these injuries in the field—a mass-casualty aspect of this subproject could be obtained by limiting the surgical support to two operating teams.
2. Subproject 4.1.2. To obtain information on the effects of combined injuries at supralethal to nonlethal ranges.
3. Subproject 4.1.3. To derive the $LD_{50/30}$ (median lethal dose in 30 days) for a large biological specimen.
4. Subproject 4.1.4. To obtain further information on missile injuries in a biological specimen.

1.5 SHOT PARTICIPATION

1.5.1 Shot Priscilla. The objectives of Subprojects 4.1.1, 4.1.2, and 4.1.4 were intended to be obtained by participation in Shot Priscilla. The early planning date was 15 April 1957; Administrative Headquarters directed that the project be operational as early as 15 March. These parameters made a predicted breeding schedule virtually impossible in the time available prior to going to the field. Further discussion resulted in a readiness date of 1 May, ±30 days, for Shot Priscilla. The shot was detonated 24 June.

1.5.2 Shot Franklin. Subproject 4.1.3 was planned for participation in Shot Franklin, because this shot was scheduled to be detonated 30 days before Shot Priscilla, and the predicted yield was satisfactory. Further, the tower cab design resulted in fractional orbital shielding of neutrons by a 9- by 9- by 3-foot sandbox along the bearing S 23° 07' 04" W. On a bearing N 16° 40' 40" W, there was a minimum of shielding.

The biological and necropsy studies could have been completed in the 30-day interval between Shots Franklin and Priscilla, thereby obtaining maximum use of professional talent in this project (which was heavily committed during Shot Priscilla).

The yield of Shot Franklin (detonated 2 June) failed to meet the expectations of this experiment and resulted in insignificant exposures at the closest station.

1.5.3 Shot Wilson. After Shot Franklin, the representatives of DOD Test Group and CETG met and decided to repeat the experiment during Shot Wilson. An advantage was that the smaller animals would gain considerable weight; the disadvantages were the lack of the sandbox for Shot Wilson and the short interval between Shots Wilson and Priscilla.

The unshielded line during Shot Wilson was on a bearing of 120 degrees true. A shielded line could be constructed only on a bearing of 204 degrees true; the neutron attenuation on this line was considerably less than the 90 percent predicted for Shot Franklin.

A pilot study of glass-missile design was also conducted during Shot Wilson (Appendix A).

The shot was detonated 18 June 1957.

1.6 SCOPE OF REPORT

In this report, each chapter describes a particular phase of the experiment that logically lends itself to a separate analysis. Each subject describes one parameter of a complicated biological specimen. Only after a total analysis of the many facets of the experiment can the stated biological objectives be derived. The data was analyzed at WRAIR by a process of professional observation and by IBM techniques, as described in Chapter 7. It is presumed that analysis of this data will result in: (1) better weapon-effect data, (2) possible extrapolation of this data to humans, and (3) methods of field medical care for nuclear casualties.

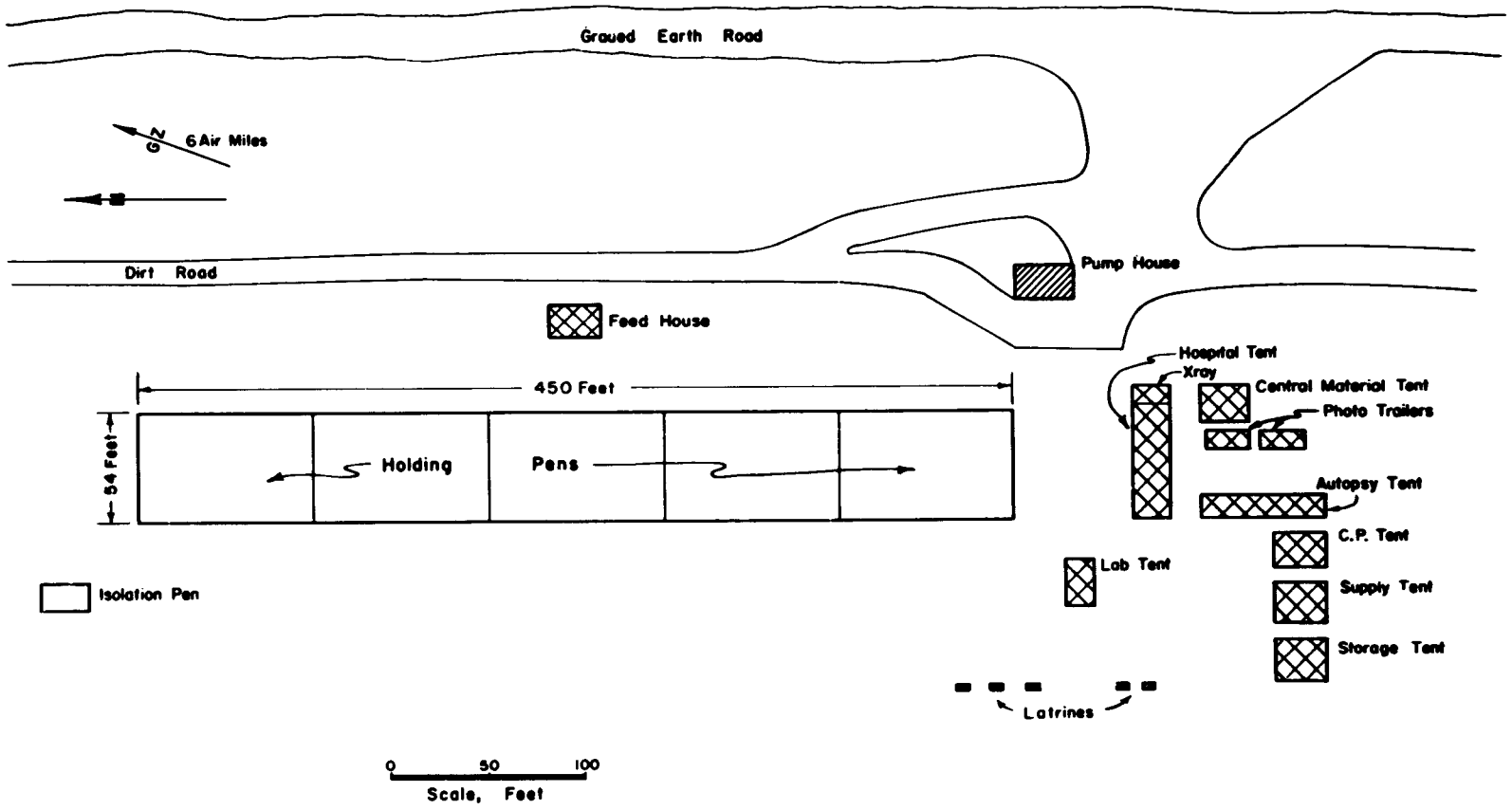


Figure 1.1 Schematic layout of animal-holding facility and hospital.

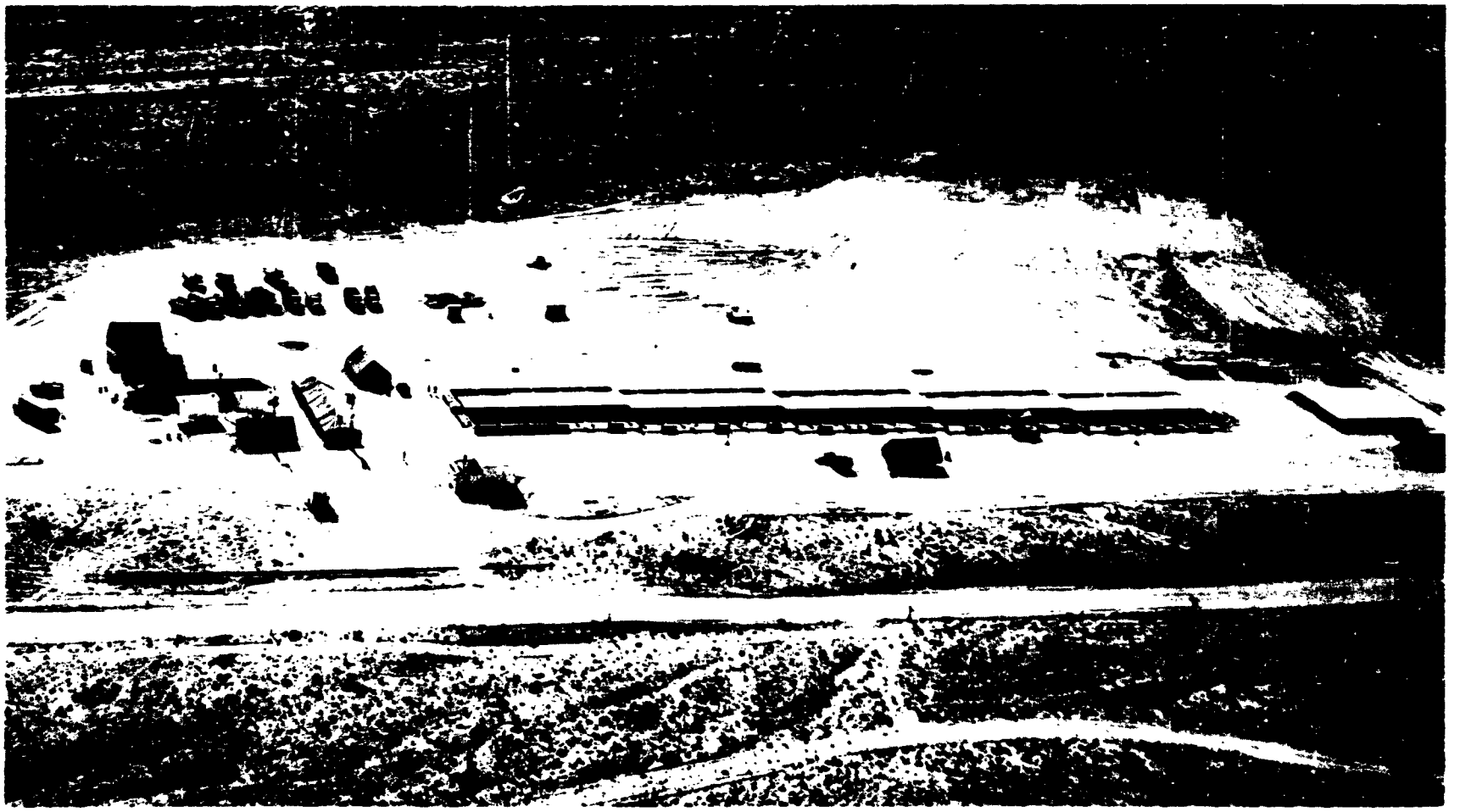


Figure 1.2 Aerial view of animal-holding facility and hospital.

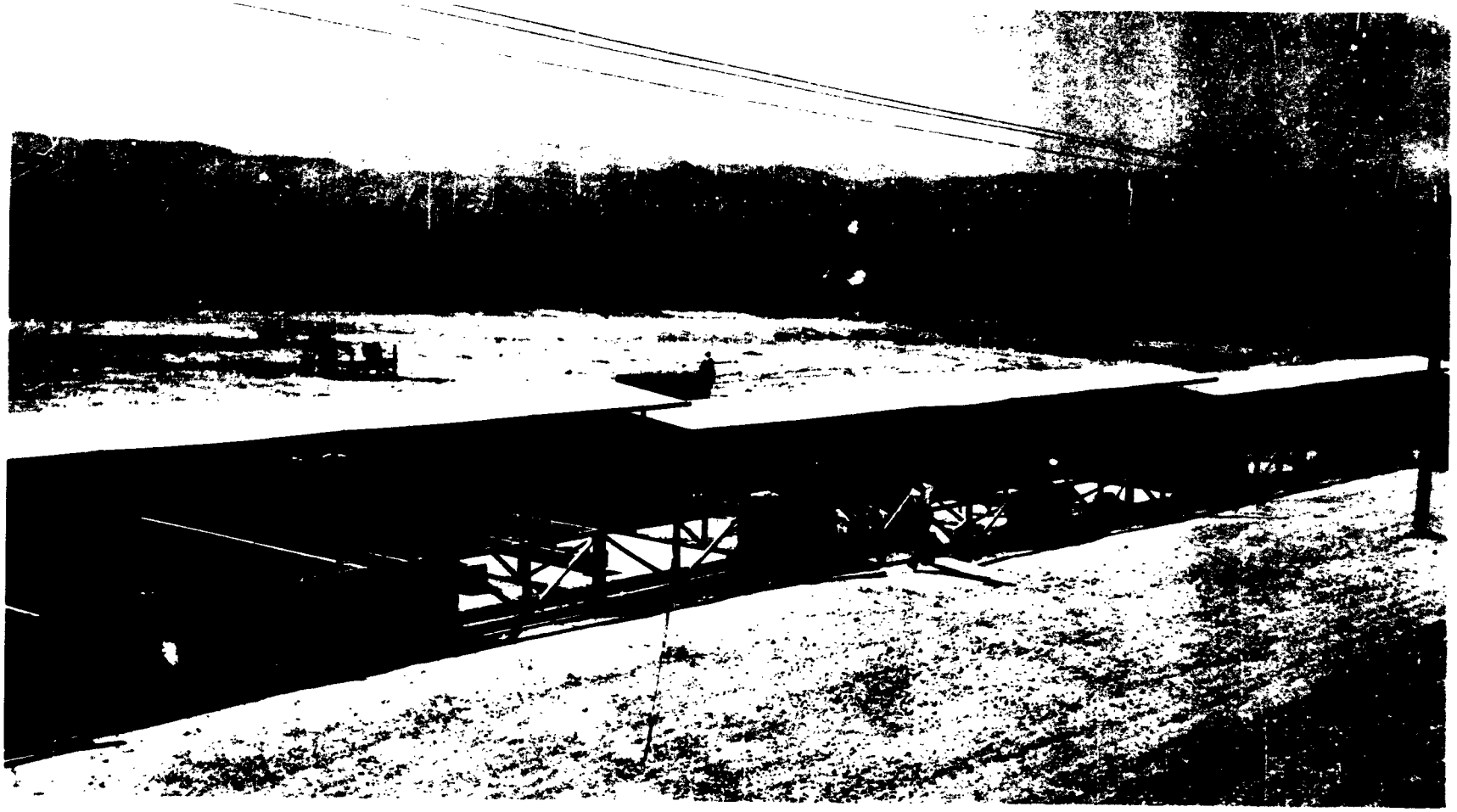


Figure 1.3 Pens for swine.

Chapter 2

RADIOBIOLOGY

2.1 OBJECTIVE

Subproject 4.1.3 was designed as an acute lethality study in pigs following neutron-gamma exposure and was performed in conjunction with the Civil Effects Test Group (CETG) as Project 39.7a. Under Program 39 of CETG it was possible to obtain neutron-gamma dose measurements during concurrent radiobiological studies on other mammalian species, as well as correlative phantom and spatial (angular) dosimetry.

2.2 BACKGROUND

Previous studies have considered the response of swine to acute whole-body irradiation from X-ray sources of 1,000 (Reference 1) and 2,000 kilovolt peak (kvp) (Reference 2). For 110- to 240-pound swine, an $LD_{50/30}$ of 510 r was reported following bilateral exposure to 1,000 kvp X rays (Reference 1). Bilateral exposure of swine of similar weight to 2,000-kvp X rays resulted in an $LD_{50/30}$ of 350 to 400 r (Reference 3). The $LD_{50/30}$ for Co^{60} gamma rays was reported as 618 r (Reference 4). The $LD_{50/30}$ for swine with an average weight of 67 pounds was estimated as 230 r after gamma exposure (Reference 5). The responsiveness of swine or other large mammals to fission neutrons or to nuclear radiations containing high neutron ratios has not been reported.

This chapter is concerned with acute lethality through 45 days after exposure, median survival time, and general observations of the radiation syndrome in swine following gamma-neutron total doses from 410 to 2,475 rep. It should be noted that the neutron-gamma ratios obtained were a function of this particular nuclear device (Shot Wilson) and tower cab shielding, and may not be referable to other devices (Reference 6).

2.3 PROCEDURE

Two hundred and sixty-four animals (47 percent male castrates, the rest female) were selected for uniformity of weight (83 ± 11 pounds) and assigned to exposure groups by a system of random numbers.

The animals were exposed in aluminum cylinders (wall thickness: $\frac{1}{4}$ inch) anchored to the ground by airplane control cables and stout metal pegs as shown in Figures 2.1 and 2.2. No ventilating system or feeding facilities were required. Animals were placed in the cylinders between 2300 and 0100 hours during the night preceding the shot. Two pigs were placed in each cylinder and twelve pigs were exposed at each dose level.

Trained personnel recovered the swine as soon as possible (H + 1 hour) after the detonation. The swine were returned to the pen area via truck, checked for radioactive contamination, and placed 24 per pen. The animals were observed at frequent intervals thereafter.

2.4 DOSIMETRY

All dosimetry was performed by personnel of CETG Program 39. Neutrons in air were measured using threshold detectors of activation foils and fission foils (Reference 7), as had been utilized in previous field tests (Reference 8). Information on dose prediction and station placement is contained in Appendix C.

The foils and the neutron energy ranges measured directly by activation or by the difference between fission thresholds were: sulfur, greater than 3.0 Mev; uranium minus sulfur, 1.5 to 3.0 Mev; neptunium minus uranium, 630 kev to 1.5 Mev; and plutonium minus neptunium, 10 to 630 kev.

Neutron fluxes at all energy bands measured decreased exponentially with distance from the detonation; however, the proportion of neutrons in the various energy ranges was unchanged over the distances at which swine were exposed. From the neutron-flux measurements, neutron doses were calculated in rep from the single collison theory (Reference 7) using the following conversion values for each neutron energy range of exposure: greater than 3.0 Mev, 2.56×10^8 n/cm^2 flux per 1 rep; 1.5 Mev to 3.0 Mev, 3.2×10^8 n/cm^2 flux per 1 rep; 630 kev to 1.5 Mev, 4×10^8 n/cm^2 flux per 1 rep; and 10 kev to 630 kev, 1×10^9 n/cm^2 flux per 1 rep.

The gamma-neutron dose ratio changed by about 8 percent over the range of animal exposures because of the shorter mean free path of neutrons as compared to gamma rays. The average neutron contribution to the total (gamma plus neutron) rep dose delivered was: greater than 3.0 Mev, 10 percent; 1.5 Mev to 3.0 Mev, 8 percent; 630 kev to 1.5 Mev, 13 percent; and 10 kev to 630 kev, 14 percent.

Gamma rays and neutrons in air were measured by means of chlorinated-hydrocarbon dosimeter systems. The characteristics of the gamma-sensitive (hexylresorcinol stabilized, tetrachloroethylene) and gamma-plus-neutron-sensitive (trichloroethylene overlayed with a water soluble indicator) chemical dosimeters have been reported in detail (Reference 8). The dosimeter vials were contained in lithium-lined aluminum cans (Figures 2.3, 2.4, and 2.5) to eliminate thermal-neutron response of the system. The chemical dosimeters were calibrated and acidimetric color changes were determined spectrophotometrically with gamma and neutron doses expressed directly in rep.

Gamma midline doses within the pig were determined by chemical dosimeters. Two chemical dosimeter vials of different range were encased in a sealed lucite cylinder, internally lined with 0.005 inch of lead (to minimize low-energy gamma response). Each cylinder also contained an uncovered gold foil in one end and a cadmium-covered gold foil at the opposite end (Figures 2.6 and 2.7). The cylinder was sutured to the anterior gastric wall along the lesser curvature, under Nembutal anesthesia and clean surgical conditions. The abdominal incision was closed by interrupted wire sutures. (Placement of the midline lucite cylinders was tested at WRAIR before Operation Plumbbob, with no evidence of untoward effects. The experience at NTS was similar, even after implantation for 60 days.)

Vaginal dosimeters, identical in construction with the intra-abdominal midline dosimeters, were also used to determine internal doses and were inserted without anesthesia the night preceding the shot. The labia were approximated by purse-string silk sutures to retain the dosimeter. The dosimeters were immediately removed upon return of the animals to the animal compound.

As a result of a series of shot postponements, the procedure was repeated on five different occasions before Shot Wilson.

Two animals per station in the closest six stations on each radius had internally placed midline and vaginal dosimeters. The depth dose measurements will be published in WT-1506 (Reference 9).

Preshot and postshot hematological studies were performed only on those animals with internally placed dosimeters and thusly subjected to the trauma of additional handling and surgery. The hematological results are reported in Chapter 5.

2.5 COURSE OF RADIATION SICKNESS IN SWINE

2.5.1 Early Post-Exposure Response. At the time of recovery (H + 1 hour), one animal (1,160-rep group) was dead as a result of a fractured cervical vertebra. Nine exposure cylinders were found partially displaced by blast. Four swine from supralethal-exposure positions were loose at the time of recovery. Although these animals acted somewhat dazed, they were ambulatory and had no burns or evidence of physical trauma. The remaining animals appeared in good condition, and there was no evidence that vomiting had occurred in any group. A few swine vomited shortly thereafter during the return trip to the pen area. On arrival at the pen area, all swine appeared to eat and drink normally.

The time of onset of the major signs of illness is recorded in Table 2.1 for the various exposure groups, and the incidence of these manifestations is presented in Table 2.2 for various times prior to death. The evidence of various signs of illness in fractional survival groups (400 to 700 rep) is shown graphically in Figure 2.8.

For the first 18 hours, post exposure, the swine appeared normal. Anorexia and moderate lethargy was observed after 18 to 24 hours at the higher doses. A few animals were noted to have soft stools at this time, but the occurrence was not related to dose.

Considerable anorexia and copious vomiting was present by H + 36 hours in groups receiving in excess of 1,900 rep. The incidence and severity of vomiting progressed rapidly in the ensuing 6 hours and was manifest by all swine receiving greater than 900 rep. Diarrhea was prominent in groups receiving greater than 1,300 rep. In the high-dose groups, there was profuse diarrhea and marked anorexia.

By late in the second day, many swine in the highest dose groups were quite ill. This was characterized by much reluctance to move on stimulation, ataxia, diarrhea, polydipsia, and repeated episodes of profuse vomiting. Although depression was noted in those groups receiving in excess of 1,300 rep, there were periods of irritability and hyperesthesia when disturbed. Fighting was easily provoked and many swine bore superficial ear wounds as a result. Irritability became more pronounced on the third day.

On the third day, anorexia was evident among all groups receiving in excess of 700 rep and was more pronounced with increasing dose. At the lowest doses, food intake was only slightly lessened, and otherwise these swine appeared normal. Diarrhea continued in the highest dose groups; however, the frequency of vomiting had subsided by late in the day. At this time, bloody stools were first noted. Also stilted gait was first observed and is best described as a hesitant podalgic walk in a stiff-legged manner, as if on stilts.

The first death occurred at H + 77 hours in an animal which received 2,185 rep. About 1 hour prior to death, this animal was observed in a sitting position violently retching with much froth accumulated about the mouth. Marked dyspnea ensued and the animal rapidly became prostrate. The rectal temperature rose to a level of 108 to 110 degrees F, and at irregular intervals tonic and clonic convulsions followed until death. This mode of exodus proved to be common.

The manifestations of acute radiation disease in swine showed three rather distinct phases after gamma-neutron exposure. In general, as the dose was increased, the onset of each phase was more rapid and the signs more pronounced.

2.5.2 Responses Associated with Exposures from 1,730 to 2,475 rep. Late on the first day after irradiation the swine showed a moderate reduction in volitional activity. At 24 hours after exposure, there was little food intake and by 36 hours, intake was nil. All animals in this dose range were vomiting within 48 hours, and the frequency and severity increased with time. Extreme polydipsia followed by copious vomiting was common. The onset of diarrhea also occurred about 48 hours after exposure, and consistency rapidly changed from soft stools to a copious watery discharge. Although polydipsia and vomiting subsided late in the third day, diarrhea persisted in most swine until death. Irritability and hyperesthesia were evident late in the second day and most pronounced on the third day. After irritability and hyperesthesia subsided late in the third day, the swine were listless and severely ill. Rectal temperatures in some swine rose to a level of 106 to 109 degrees F. In keeping with the gaunt appearance of the animals was the measured decrease in body weight.

The mode of death varied in this range of exposure doses. Many swine died quietly in deep coma, whereas others had repeated episodes of convulsive activity for several hours prior to death. The time of death ranged from 106 to 112 hours. This was similar to the stable 3.5- to 4-day or gastrointestinal death seen in rodents after X- and gamma-ray exposures from 1,200 to 10,000 r.

2.5.3 Responses Associated with Exposures from 575 to 1,535 rep. Anorexia and vomiting occurred later than for the previous group, and their incidence, severity, and duration were not marked in the early stages. Vomiting became severe later for those with the higher doses, with some swine vomiting gross blood. Most of these swine had a transient return of appetite between the fifth and seventh days, yet became gaunt and emaciated with a rough hair coat prior to death.

The onset of diarrhea occurred on the fourth and fifth days. In many swine, bloody stools were noted by the end of the first week. Blood clots and gross blood were passed with considerable straining in some animals, while others bled freely while lying down.

By the seventh day, bloody froth and bright red blood exuded from the nostrils in many swine. The onset of cutaneous petechiae and/or purpura was noted from the eighth to the twelfth day, appearing on the ventral surface of the abdomen or the medial aspects of the extremities. These areas developed a livid appearance as the hemorrhagic lesions coalesced. A similar lividity was seen in the ears in the terminal stages of the illness. Frequently, swine in this group survived three or four days after the onset of bleeding. Edema of the extremities and rarely of the snout, not seen at higher doses, appeared from the seventh to the twelfth day.

Gross and ophthalmoscopic observations revealed only extreme congestion of the sclera in both hemorrhagic and nonhemorrhagic swine throughout the illness.

2.5.4 Responses Associated with Exposures from 410 to 515 rep. The syndrome associated with median lethal doses was characterized by a transient loss of appetite, and vomiting and diarrhea occurred about the third day. This was followed by a period of apparent normal health and continued weight gain until the appearance of the hemorrhagic syndrome at 8 to 10 days following exposure. Hemorrhagic signs were more pronounced in those animals that eventually succumbed, yet which lived sufficiently long for manifestations of granulocytopenia and thrombocytopenia to develop fully. Bleeding from body orifices, elevated temperature, and ataxia were significantly more frequent in decedents. Death usually occurred on the fourteenth or fifteenth day, and this phase of radiation sickness has been described in detail for a variety of experimental animals.

2.6 LETHALITY

Listed in Table 2.3 are the percent deaths at 30 days for swine exposed during Shot Wilson to graded doses of neutrons and gamma rays. When percent mortality was plotted against dose, a sigmoid response curve was obtained. Probit transformation of the data, using the method described in Reference 10, gave a regression line of the type

$$Y = a + bX$$

where Y was the probit of percent mortality and X was log radiation dose in rep. Figure 2.9 shows the relationship of probit of percent mortality for varying doses of neutron plus gamma irradiation. Median lethal doses at various times after exposure are given in Table 2.4. The LD_{50} at 45 days was not altered from the 30-day value by the death of the one animal at the forty-second day.

2.7 MEDIAN SURVIVAL TIME

Median survival time at each dose level was determined by plotting probit of percent survival against the logarithm of time after exposure. The best line of fit was drawn through the data, and the point corresponding to probit 5, or 50 percent survival, was taken as the median survival time. For swine exposed to graded doses of neutrons and gamma rays, the median survival times are listed in Table 2.3.

Although the weather at NTS was unsettled, the wide temperature differentials seemed to have no significant effect on the time of death of irradiated swine. Table 2.5 lists the number of animals dying at various time intervals during the day, for the first 189 deaths observed. There was no wave of deaths or large increase in percent deaths at any time interval during the day to suggest that the time of death was influenced by the environmental temperatures encountered at NTS. Every means available was utilized, however, to reduce the adversities of the weather; these measures included maintaining a constant supply of cool drinking water, shading, and frequently hosing of the pens to decrease floor temperature.

Shown graphically in Figure 2.10 are survival times for swine obtained in this study along with survival data for mice, rats, and monkeys exposed to rapidly delivered Ba^{140}-La^{140} gamma radiation (1.2 to 1.4 Mev of energy) as reported in Reference 11.

2.8 BODY WEIGHT RESPONSE

Body weight loss has been used as a measure of radiation effect on small animals (Reference 12) and has been employed in the field to compare biological effectiveness of gamma rays and neutrons (Reference 8).

Weight change in the pig was tested as a measure of radiation exposure during Shot Wilson (Table 2.6). The optimal time for correlation of dose and change in body weight proved to be 3 days after irradiation. Figure 2.11 shows the relationship of percent weight change of swine 72 hours post irradiation and log dose of exposure.

2.9 DISCUSSION

The physical signs of acute sickness in swine exposed to a wide range of gamma-neutron doses from a nuclear detonation have been described. Although fission neutrons

contributed about 45 percent of the total dose delivered, there was little difference in the incidence, severity, and duration of acute radiation sickness in swine as compared to X or gamma irradiation (References 1, 2, 4, 12, 13, and 14).

Podalgia and abnormal gait were observed as reported in swine after Co^{60} irradiation (Reference 12) and may be associated with hemorrhage into joint spaces as observed in this study and as reported in Reference 13. Ocular lesions reported after low-dose-rate exposures to Co^{60} gamma rays (Reference 12) were not observed, however.

The LD_{50} value of 486 rep at 30 days is in good agreement with values reported for swine and other large mammals after X or gamma irradiation (References 1, 2, and 4). Considering the variations in biological responses and differences in exposure factors reflected in the $LD_{50/30}$ values obtained, the differences were, indeed, not large. The previously reported value of 230 r for swine exposed to gamma rays from a nuclear device (Reference 5) was significantly lower. In the present study, neither gamma rays nor fission neutrons were obtained as discrete radiations. However, the potency of fission neutrons can be deduced by assigning an effectiveness of 1 for gamma rays and by assuming that the effect of gamma plus neutron irradiation is additive. The potency of fission neutrons as compared to gamma rays for the production of lethality is, then, the gamma-neutron ratio, or about 1.2.

The survival times of irradiated swine were similar to those seen from rodents and monkeys (Figure 2.10) over the same range of doses; however, quantitative differences appeared to exist between swine and the other species. The median survival time for swine, irradiated with doses about the median lethal range, was 14 to 15 days as compared to the 10 to 11 days for rodents. The dose-dependent region of survival response occurred in swine after doses from 575 to 1,535 rep. A stable plateau in survival time of 4 to 5 days appeared to have been reached for the swine at somewhat higher total doses than for the gastrointestinal death at $3\frac{1}{2}$ days in rodents and monkeys. Because no group of swine had a median survival time less than 4 to 5 days, the threshold for central nervous system death was not exceeded and has been reported (Reference 15) in excess of 2,475 rep.

In Figure 2.11, there is considerable scatter in some of the weight measurements; however, the composite data suggest that changes in body weight at 72 hours post exposure in the pig can be used to predict the exposure dose within useful limits.

2.10 SUMMARY

The responsiveness of 264 swine exposed to doses from 410 to 2,475 rep of gamma-neutron irradiation containing high neutron ratios has been described.

The LD_{50} value at 30 days was 486 (478 to 496) rep.

The median survival times for swine were similar to those of other mammalian species.

The potency of fission neutrons as compared to gamma rays was about 1.2 for the production of lethality at 30 days in swine.

2.11 FOLLOWUP STUDIES

The survivors of radiation exposure during Shot Wilson, survivors of significant doses of radiation from Shot Priscilla, and control swine were air transported without mortality to WRAIR 30 days after Shot Wilson. There was hematological recovery in 2 months at dose levels less than 268 rep, recovery in 4 months at doses less than 410 rep, and

recovery in 7 months at doses less than 615 rep. Four months after exposure during Operation Plumbbob (about 268 rep), 48 swine were irradiated with varying doses of 3.5 Mev Van de Graaff X rays (Reference 16). The $LD_{50/30}$ of 520 r was not significantly different from that obtained for primary exposure. The radiation sickness was the same as observed during Operation Plumbbob.

On 1 August 1959, the 2-year survivors of Operation Plumbbob were shipped to the University of Tennessee—Atomic Energy Commission Agricultural Research Facility, Oak Ridge, Tennessee, for observation throughout their remaining life span.

TABLE 2.1 TIME OF ONSET OF MAJOR SIGNS OF RADIATION SICKNESS

Dose in rep	Vomiting	Anorexia	Diarrhea	Temperature*	Stilted Gait	Depression	Ataxia	Petechiae and/or Purpura	Bleeding Body Orifices	Edema
2,475	H+36	H+24	H+42	D+3	D+2	D+2	H+42	D+6	†	—
2,185	H+36	H+36	H+42	D+3	D+3	D+2	‡	D+5	—	—
1,935	H+36	H+24	H+42	D+2	D+3	D+2	‡	—	—	—
1,730	H+48	H+36	H+42	D+2	D+3	D+2	D+3	—	D+4	—
1,535	H+48	H+51	H+42	D+3§	D+3§	D+2	D+4	D+4	—	—
1,325	H+42	H+51	H+48	‡	‡	D+2	‡	‡	‡	‡
1,300	H+42	H+51	D+2	D+3	D+5	D+2	D+5	—	—	—
1,205	H+42	H+42	H+42	‡	‡	D+2	‡	‡	‡	‡
1,160	H+42	H+42	D+2	D+4	D+5	D+2	D+5	D+5	—	—
1,070	H+42	H+51	H+42	‡	D+14	D+2	‡	—	—	—
1,030	H+42	H+51	D+2	D+2	D+4	D+2	D+7§	—	D+7	—
955	H+42	H+51	H+42	‡	D+9	D+2	D+11	D+9	—	D+12
915	H+48	H+51	D+2	D+4	H+51	D+2	D+4	D+8	D+8	—
845	H+48	H+51	H+72	‡	D+10	‡	D+7	—	D+8	—
820	H+48	H+51	D+4	D+4	D+3	D+3§	D+4	D+14	D+8	D+7
760	H+48	H+74	H+72	‡	D+12	‡	D+7	D+12	—	D+12
730	H+48	H+74	D+4	‡	D+4§	D+4§	D+9	D+8	D+9	—
645	‡	‡	‡	‡	‡	‡	‡	D+8	D+9	D+10
575	‡	‡	‡	‡	—	‡	—	D+8	D+9	D+12
515	‡	‡	‡	‡	D+7§	‡	D+11	D+8	D+19	D+11
455	‡	‡	‡	‡	D+12	‡	D+10	D+8	D+9	D+10
410	‡	‡	‡	‡	D+11	‡	D+14	D+10	D+11	D+13

* More than 10 percent of swine with 105.5 degrees F.

† Not seen.

‡ Insufficient data.

§ At least this early.

TABLE 2.2 INCIDENCE OF SIGNS OF RADIATION SICKNESS AT VARIOUS TIMES PRIOR TO DEATH

Signs of Radiation Syndrome	Dose in rep	Day Prior to Death				
		1*	2*	3*	4*	5*
Depression	1,700 to 2,475	32/39	48/48	38/40	7/8	†
	1,000 to 1,700	21/21	25/25	32/32	29/29	15/17
	700 to 1,000	27/33	19/28	15/23	14/19	14/19
	410 to 700	33/35	33/34	25/33	22/33	19/25
Rectal temperature 105.5 degrees F	1,700 to 2,475	16/39	16/48	6/40	2/8	†
	1,000 to 1,700	17/21	16/25	8/32	7/29	5/17
	700 to 1,000	26/33	22/28	14/23	5/19	3/19
	410 to 700	27/35	19/34	16/33	12/33	12/25
Diarrhea	1,700 to 2,475	35/39	37/48	28/40	4/8	†
	1,000 to 1,700	15/21	19/25	23/32	20/29	12/17
	700 to 1,000	†	†	†	†	†
	410 to 700	†	†	†	†	†
Petechiae and/or purpura	1,700 to 2,475	2/39	0/48	0/40	0/8	†
	1,000 to 1,700	2/21	0/25	0/32	0/29	0/17
	700 to 1,000	9/33	4/28	1/23	1/19	0/19
	410 to 700	22/35	16/34	12/33	10/33	4/25
Bleeding body orifices	1,700 to 2,475	1/39	0/48	0/40	0/8	†
	1,000 to 1,700	3/21	1/25	0/32	0/29	0/17
	700 to 1,000	8/33	4/28	2/23	1/19	1/19
	410 to 700	13/35	12/34	3/33	4/33	1/25
Edema	1,700 to 2,475	0/39	0/48	0/40	0/8	†
	1,000 to 1,700	0/21	0/25	0/32	0/29	0/17
	700 to 1,000	1/33	2/28	2/23	2/19	1/19
	410 to 700	14/35	12/34	8/33	4/33	1/25
Stilted gait	1,700 to 2,475	2/39	4/48	1/40	1/8	†
	1,000 to 1,700	4/21	4/25	2/32	0/29	1/17
	700 to 1,000	3/33	1/28	2/23	1/19	2/19
	410 to 700	3/35	6/34	10/33	5/33	0/25
Ataxia	1,700 to 2,475	3/39	0/48	0/40	0/8	†
	1,000 to 1,700	9/21	1/25	0/32	0/29	0/17
	700 to 1,000	7/33	4/28	2/23	1/19	1/19
	410 to 700	18/35	10/34	4/33	0/33	0/25
Moribund	1,700 to 2,475	7/39	0/48	0/40	0/8	†
	1,000 to 1,700	0/21	0/25	0/32	0/29	0/17
	700 to 1,000	3/33	0/28	0/23	0/19	1/19
	410 to 700	5/35	0/34	0/33	0/33	0/25

* Number positive/number examined.

† Insufficient data.

TABLE 2.3 PERCENT OF DEATHS OF SWINE 30 DAYS AFTER SHOT WILSON

Dose in Air		Number of Swine Dying Per Day																				Number	Percent	Survival Time in Hours	
rep	Gamma/ Neutron	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	42	Dying/Exposed	Lethal*	Median	Min to Max
2,475	1.05				1	10	1																12/12	100	106	80 to 123
2,185	1.08				1	11																	12/12		107	77 to 119
1,935	1.10				2	6	4																12/12		112	85 to 140
1,730	1.13				3	6	3																12/12		109	82 to 124
1,535	1.16					3	7	1	1														12/12		125	99 to 169
1,325	1.19					2	7	3															12/12		134	118 to 166
1,300	1.03					3	5	2	1		1												12/12		137	106 to 226
1,205	1.21				1	1	5	1	3	1													12/12		139	88 to 195
1,160	1.05	1†					6	3	2														12/12		143	128 to 191
1,070	1.25					1	3	2	3	3													12/12		156	129 to 204
1,030	1.08					2	2	4	2	2													12/12		147	113 to 195
955	1.27						1	2	2	1	1	2	2				1						12/12		210	127 to 367
915	1.10							5	2	4			1										12/12		180	146 to 266
845	1.31							3	5	3		1											12/12		178	151 to 256
820	1.12							2	5	2	2											1	12/12	91.7	182	150 to 225‡
760	1.34						1	2	3	1			2						1				10/12	83.3	182	133 to 423
730	1.15							1	2	1	5	1			2								12/12	100	218	146 to 314
645	1.18										1	2	4	3		1	1						12/12	100	273	239 to 365
575	1.21								1	1		3	2			1	1		1				10/12	83.3	270	180 to 429
515	1.24											1		1		2	1		1		1		7/12	58.3	350	260 to 467
455	1.27													1			1		1	1			4/12	33.3	360	289 to 436
410	1.28															1	1						2/12	16.7	360	340 to 380

* At 30 days.

† Animal dead on recovery. (Not included in lethality or survival time results).

‡ Not including animal dying at 42 days.

TABLE 2.4 MEDIAN LETHAL DOSE AT VARIOUS TIMES AFTER EXPOSURE

Time After Exposure	Median Lethal Dose
day	rep
5	1,570 (1,439 to 1,714)
10	711 (662 to 764)
15	565 (514 to 621)
30 to 45	486 (478 to 496)

TABLE 2.5 NUMBER OF SWINE DYING AT VARIOUS TIME INTERVALS DURING THE DAY

First 189 deaths.

Time of Death	Number Swine	Percent Dying
0001 to 0400	32	16.9
0401 to 0800	40	21.2
0801 to 1200	35	18.5
1201 to 1600	28	14.8
1601 to 2000	33	17.5
2001 to 2400	21	11.1
		$\bar{x}$ = 16.7

TABLE 2.6 PERCENT OF ORIGINAL WEIGHT OF SWINE DYING AT VARIOUS TIMES AFTER EXPOSURE

Dose in rep	Days																	$\bar{x}$
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
	Percent of Original Weight at Time of Death																	
2,475	74.	85.	87.															85.
2,185	92.	92.																91.
1,935	94.	86.	88.															88.
1,730	87.	90.	89.															89.
1,535		85.	92.	93.	88.													89.
1,325		87.	88.	91.														88.
1,300		88.	86.	88.	91.		87.											87.
1,205	87.	90.	80.	86.	85.	78.												83.
1,160			88.	86.	88.													88.
1,070		86.	82.	86.	96.	92.												89.
1,030		88.	92.	88.	88.	90.												89.
955			95.	93.	90.	89.	94.	97.	97.				97.					93.
915				88.	84.	86.												86.
845				96.	91.	96.		88.										93.
820				100.	94.	92.	99.											96.
760			95.	89.	94.	100.		94.							92.			93.
730					88.	92.	94.	92.			90.							92.
645							106.	92.	94.	96.	87.	86.						94.
575				94.	88.			101.	100.			98.	104.		107.			99.
515										101.		93.		96.	96.		92.	95.
455										94.			91.		98.	93.		94.
410												94.	98.					96.

Figure 2.1 Exposure cylinders on Yucca Flat.

Figure 2.2 Exposure cylinder showing cables and stakes for anchorage.

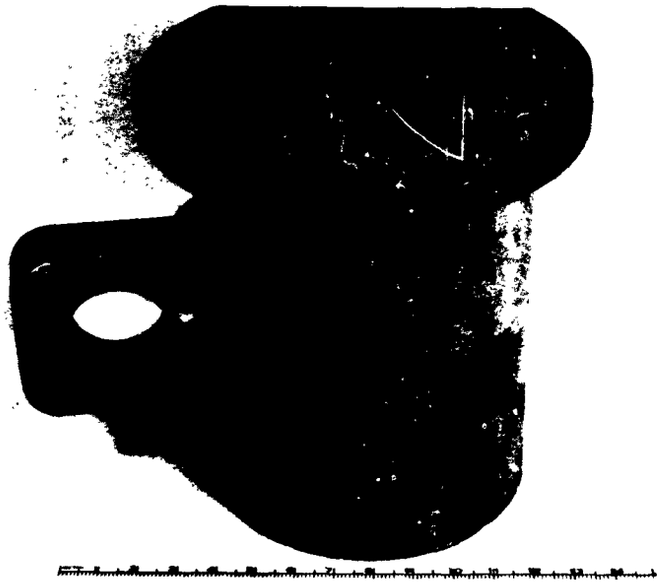


Figure 2.3 Assembled aluminum can for chemical dosimeters.

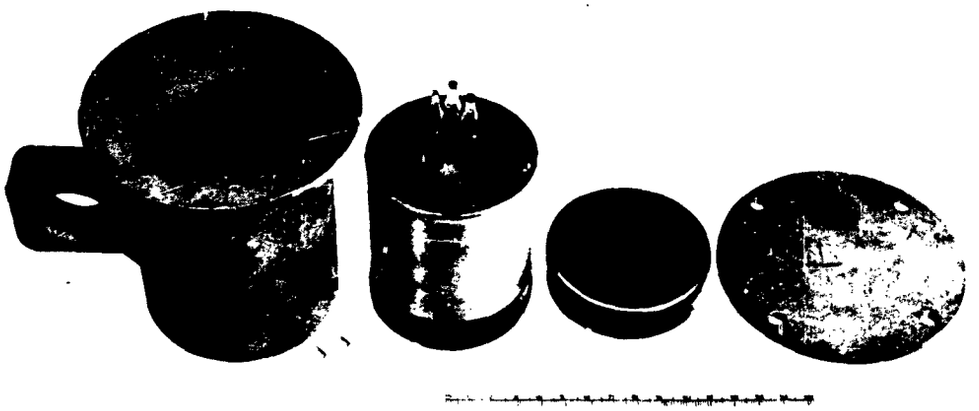


Figure 2.4 Dosimeter components.

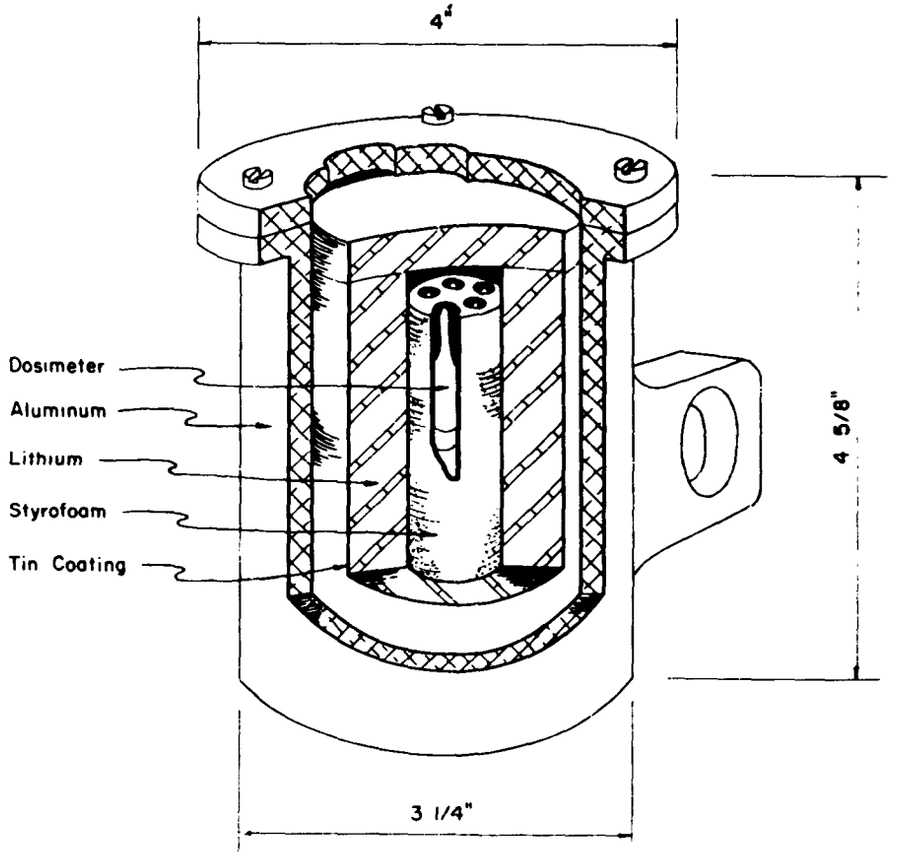


Figure 2.5 Schematic drawing of chemical dosimeter with aluminum protective can, lithium insert, and glass vials containing organic chemical detector.

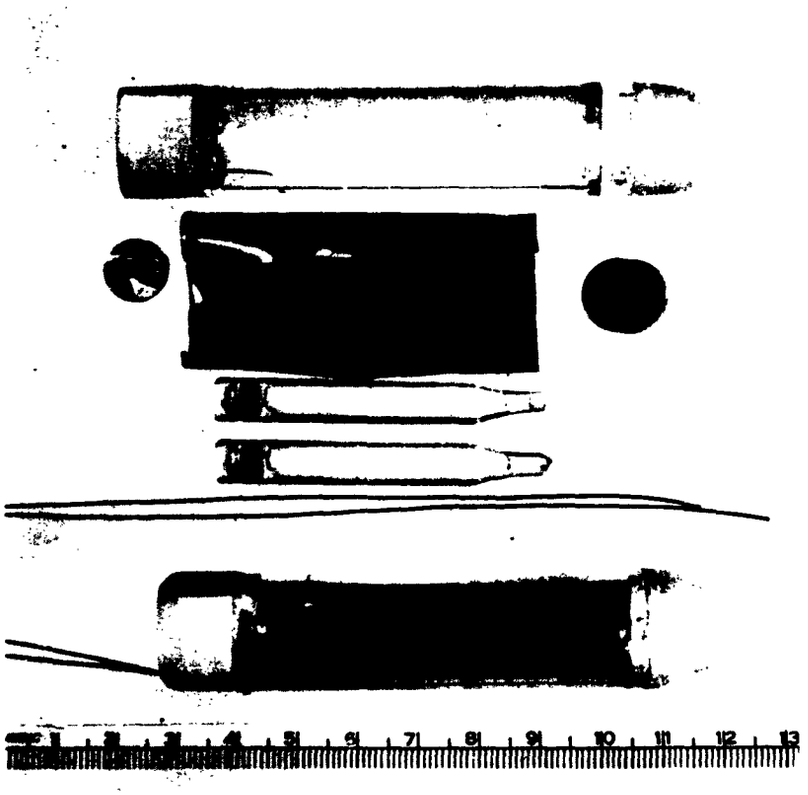


Figure 2.6 Intra-abdominal and/or intravaginal dosimeter.

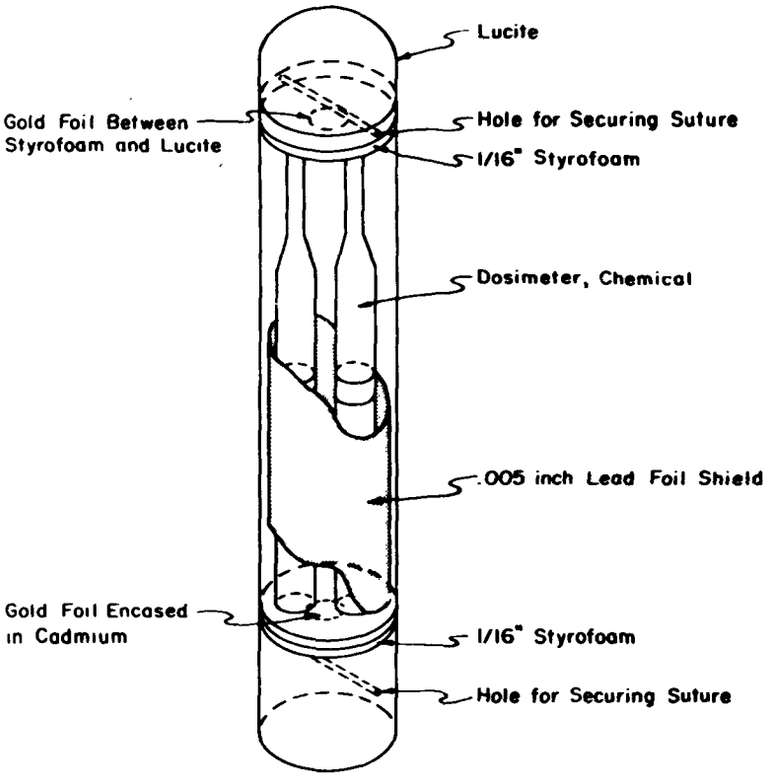


Figure 2.7 Schematic drawing of internal dosimeter.

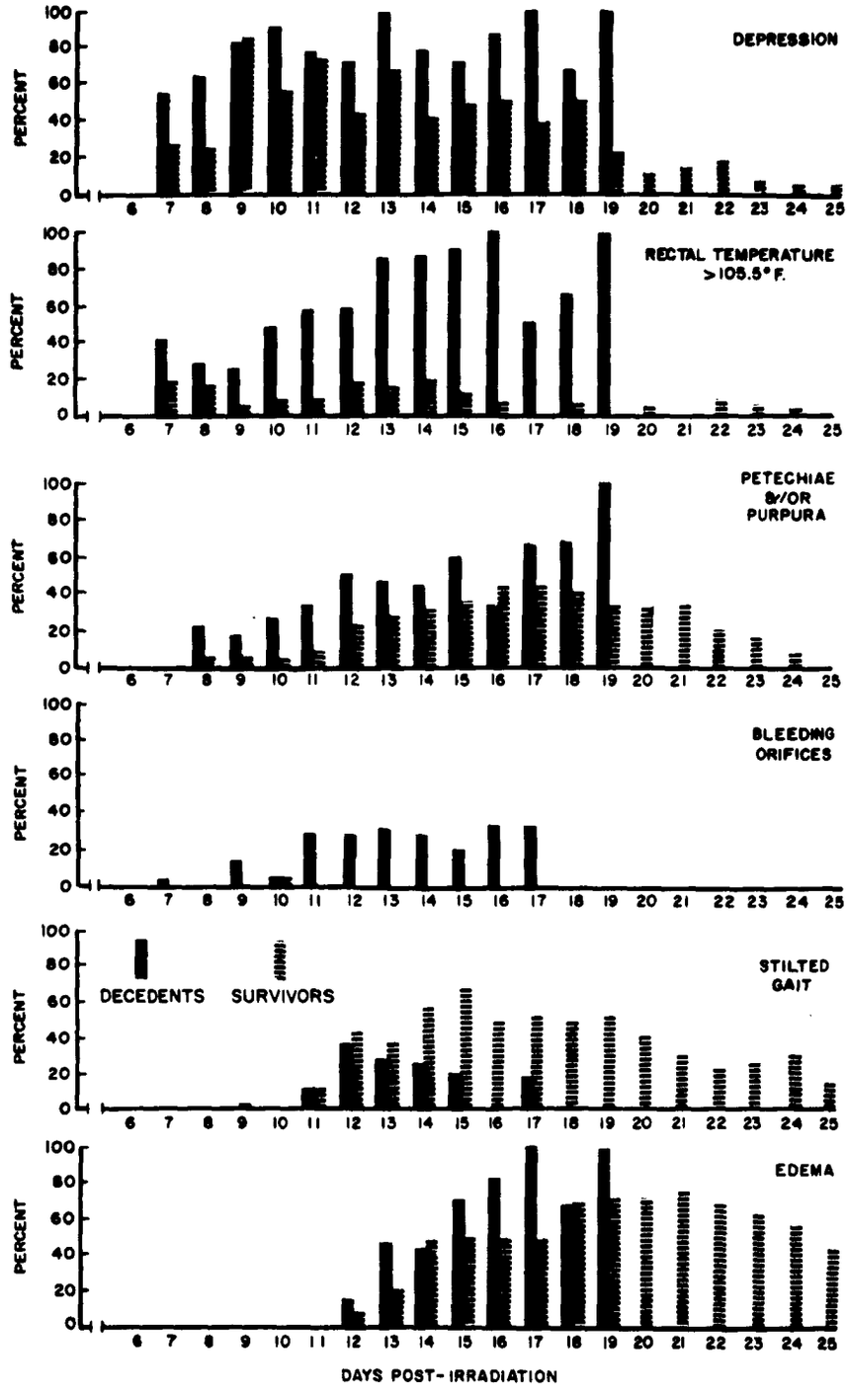


Figure 2.8 Incidence of selected signs in fractional survival groups 7 to 25 days post irradiation.

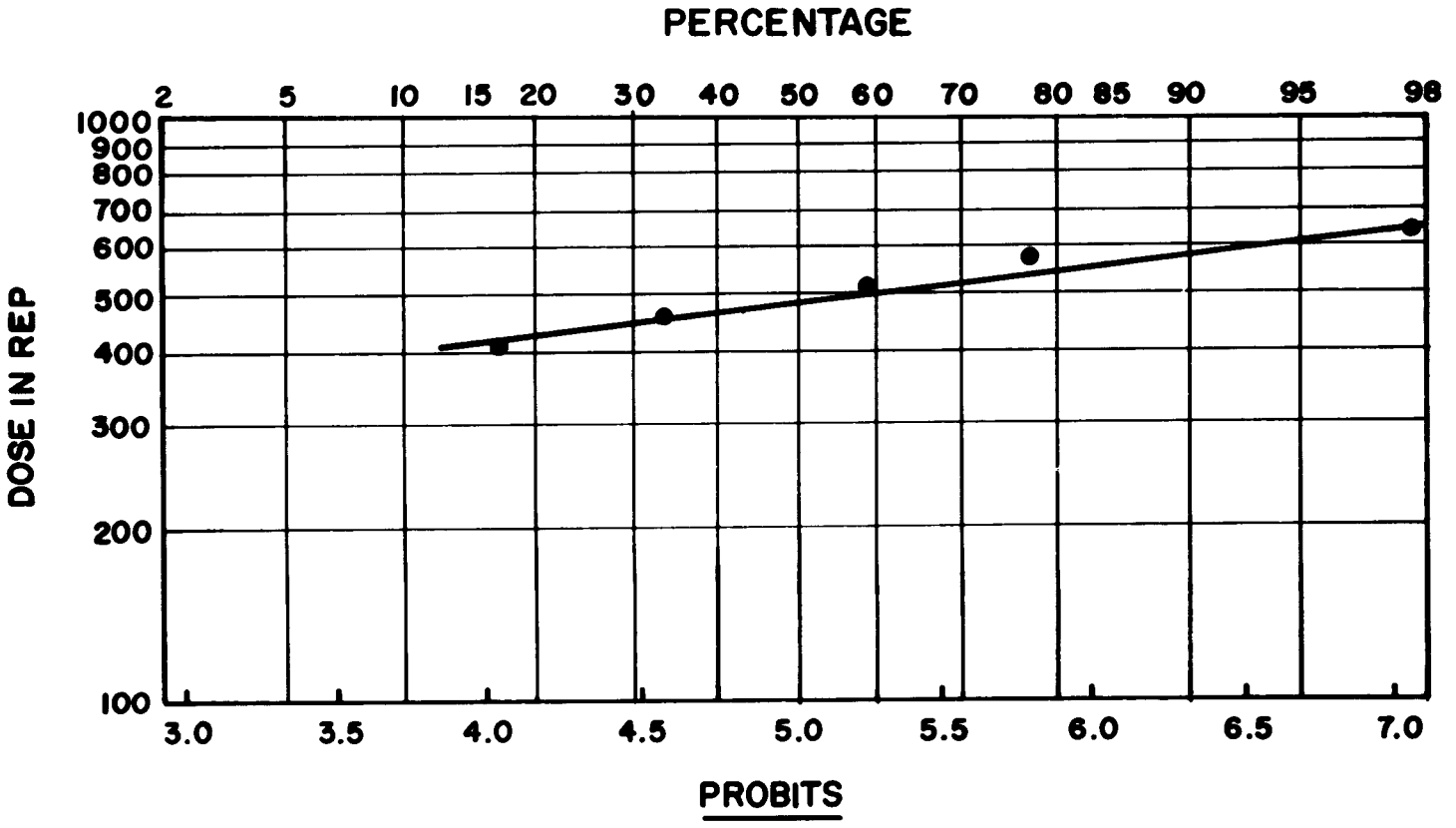


Figure 2.9 Thirty-day mortality in swine for varying doses of gamma-neutron irradiation from a nuclear device.

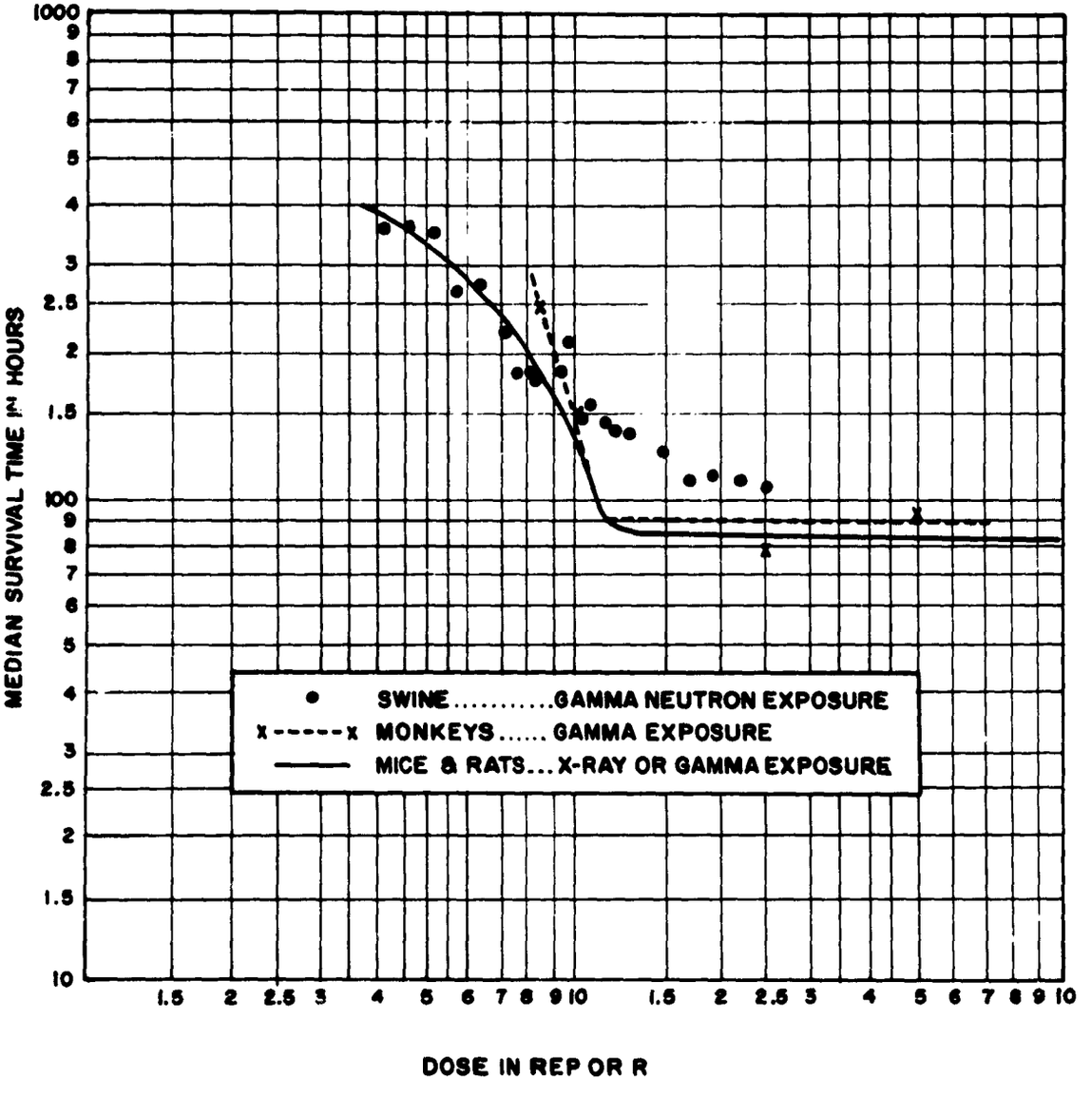


Figure 2.10 Median survival time of mice, rats, monkeys, and swine after exposure to X, gamma, or gamma-neutron flux of a nuclear device.

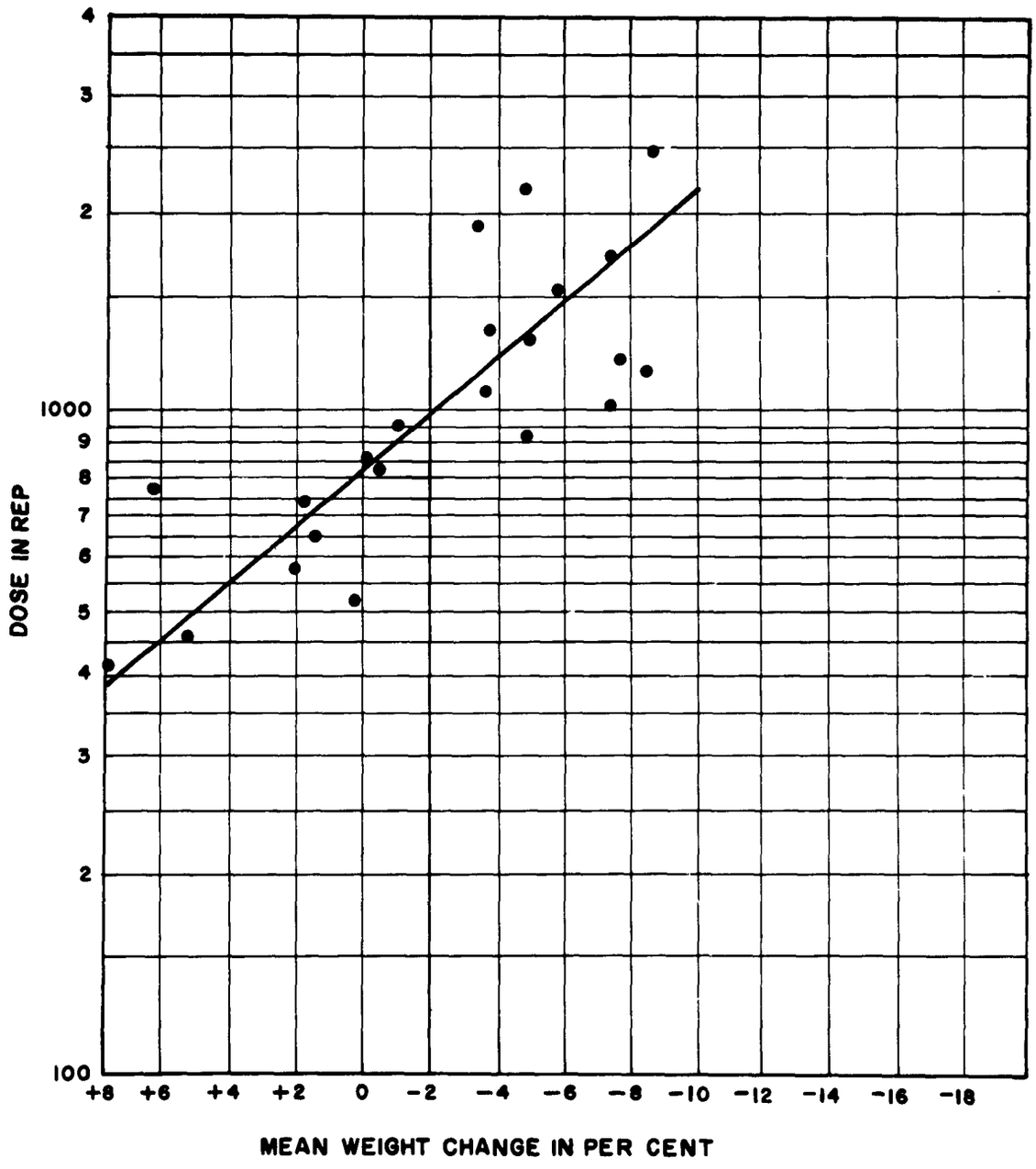


Figure 2.11 Weight changes in swine 72 hours after exposure to the gamma-neutron flux of a nuclear device.

Chapter 3

SURGERY AND WOUND MANAGEMENT

3.1 OBJECTIVE

What part medical and surgical treatment will play in the management of survivors from a nuclear detonation is still problematical, because many gaps exist in the knowledge of therapy for survivors of such an explosion.

The primary question is whether survivors who have received significant total-body irradiation should be treated according to TB-MED-147 (Reference 17) or whether they should be treated in accordance with the concept of mass-casualty treatment outlined in TB-Med-246 (Reference 18). The military significance of this question is of the utmost importance.

Another question is whether the medical service should continue to support tactical units with complicated groups equipped to carry out definitive diagnosis and treatment, or whether these services should be placed in more rearward zones with merely first-aid and evacuation elements in support of the tactical units. It was hoped that this study would solve some of the problems—in particular, those related to the tolerance to surgery after exposure to the nuclear detonation and those related to débridement and secondary closure of wounds.

The basic objective was to determine the response of a large biological specimen, weighing 75 to 100 pounds, to multiple trauma—whole-body irradiation and thermal and missile exposure—from a nuclear detonation and the response of the animal to outlined forms of treatment. As mentioned previously, the swine was selected as the specimen. How much of the data relative to treatment can be extrapolated to the human is problematical—probably little, because of the extensive tolerance and resistance of the swine to trauma, in contradistinction to the human. But it was felt that significant diagnostic studies could come from the project. These were principally related to the response of a large biological specimen to wounding plus mixed neutron and gamma irradiation from a nuclear detonation, and to the exploration of certain laboratory parameters that would better enable evaluation of the clinical response to wounding and total-body irradiation. The diagnostic studies might then be used as guides for treatment.

3.2 EXPERIMENTAL STUDIES

Nothing exists in the medical literature on the response of the swine to wounding with missiles. It became obvious after an extensive preliminary study, with Hampshire, Yorkshire, and Red Duroc swine weighing 45 to 70 pounds, that swine are extremely tolerant of abdominal wounds involving both the small and large bowel. Definitive surgical treatment of these wounds changed overall survival rates little. However, this was not true of the gastric wound. Perforations of the stomach, created by excising under direct vision at laparotomy a button of anterior gastric wall, uniformly resulted in death. Permanent survivors could be obtained from this wound if repair was carried out as long

as 5 hours after injury. Of 18 swine subjected to standardized missile wounds of thorax and abdomen, 55.5 percent survived after 30 days without treatment. A similar group of animals with nearly identical wounds of the lower thorax and abdomen subjected to resuscitation and definitive surgical treatment had a 30-day survival of 63 percent. This difference of 7.5 percent was not felt to be clinically significant, particularly in view of the extensive resuscitation and surgical treatment carried out in the treated group.

An evaluation of the morbidity of swine exposed to compound chest injury demonstrated that swine tolerated well a tension pneumothorax complicated by hypovolemia (bleeding to clinical shock). In addition, blood alone and blood plus virulent organisms, when inserted into the pleural space without definitive treatment, were tolerated well.

Mortality-dose curves for swine have been worked out in References 7 and 8 for the 1,000-kvp and 2,000-kvp machines. In addition, Reference 19 evaluated the mortality in swine exposed to gamma radiation from a nuclear weapon and "...assumed from data available that swine have the same resistance to total-body irradiation as human beings." For a 70-pound swine, Reference 19 lists the LD_{100} as 390 r, LD_{50} as 230 r, and LD_0 as 130 r. Background studies carried out at WRAIR were inconsistent. With the 2,000-kvp machine at the Clinical Center, National Institutes of Health, studies resulted in the impression that 500 r of total-body irradiation was an $LD_{70/30}$ and 400 r an $LD_{50/30}$. In an attempt to evaluate compound trauma, 20 swine, weighing approximately 45 pounds each, were subjected to total-body irradiation, 325 r, and then wounded with a standard weapon giving penetrating low thoracic and upper abdominal wounds. Half of these animals underwent definitive surgical treatment. When these two groups of irradiated animals were compared to nonirradiated groups, both treated and untreated and suffering similar thoracic and abdominal wounds, there was no significant change in the clinical course of the wounded animals. The surgical wound of exploration was noted to heal per primam in that group operated.

The response of the swine to thermal radiation was evaluated for the study. Fifteen animals were subjected to thermal trauma with a weed burner that would deliver a measured dose, recorded by a thermocouple beneath the skin, of approximately 100 cal/cm^2 of skin and subcutaneous tissue. The 15 animals were followed for a 5-week period. Five animals had 30 to 35 percent of total-body surface burned, and 10 were burned over 50 percent and up to 80 percent of their total-body surface area. All the swine failed to show the physiologic response expected to this extent of thermal trauma. In the lesser-burned pigs, the animals were walking about their cages on the first day after being burned. In the more extensively burned pigs, the encircling eschar inhibited their activity. Most of the pigs eventually cracked this immobilizing eschar sufficiently so that they were able to stand and take food.

The pertinent features gained from this background study dealing with thermal trauma in the swine were as follows: (1) it was impossible to kill the swine with a full thickness burn of up to 80 percent of the total-body surface; (2) the ability of the pig to withstand thermal trauma was exceedingly great and in no way paralleled the human response; and (3) both gross and microscopic examination of the sacrificed animals substantiated current work showing that the swine was extremely resistant and unresponsive to controlled trauma and secondary infection. It was the opinion of the investigators that little could be gained by subjecting the swine to thermal trauma alone; however, the animal might be an ideal subject on which to evaluate the combined effect of both thermal trauma and irradiation injury. Any mortality following combined injury would be significant.

In the laboratory, the effect of total-body irradiation on simulated missile wounds (massive wounds) of the ham was evaluated. The clinical course of the wound was not

changed over that of the nonirradiated animal. However, in the swine subjected to 500-r total-body irradiation plus a massive ham wound, a problem was observed that confirmed some of the observations in Reference 20, where it was noted that healing of local burns occurred in animals who subsequently died of total-body irradiation. During the course of epithelialization of the burns, these were biopsied. The sites of biopsy subsequently broke down and became infected and even gangrenous. In the swine subjected to 500-r total-body irradiation plus a massive ham wound, the course of the ham wound was unchanged from that in the nonirradiated animals. However, these animals, because they could not mobilize the wounded extremity with facility, incurred minor wounds by trauma against the cages. These seemingly insignificant wounds became infected from the fourth to the sixth day after irradiation and spread to the entire limb of the animal and contributed remarkable morbidity.

3.3 SURGICAL PROGRAM

3.3.1 Glass Missile Study. It was planned to utilize 100 swine selected by trained personnel from the animal inclosures for Shot Priscilla, where the overpressures were expected to be sufficient to produce the desired wound for study—a penetrating wound of the low thorax or upper abdomen that experience had shown would give the greatest possibility of a laceration of the stomach. The lacerated stomach wound was the only one in which mortality could be influenced by definitive surgical treatment.

On the arrival of the wound-analysis teams at Stations 6 and 7 (Table 7.1) where the probability of the required injuries (from glass missiles) was expected to be the greatest, numerous animals were seen lying about and running about with extruded portions of small bowel and/or omentum. These animals with this type of injury and still alive, were immediately evacuated to the treatment facility, as were any other animals believed to have intraperitoneal injuries. All told, from Stations 6, 7, and 8, some 60-odd animals must have been evacuated with either intraperitoneal contents extruded or a diagnosed penetrating abdominal or thoraco-abdominal wound.

Unfortunately, because of the heat, dust, and cannibalization of severely wounded animals by those wounded less severely, only a small fraction of those evacuated with extruded viscera survived to reach the triage platform. The original concept was that these animals with abdominal wounds would be alternately divided between treatment (TB-Med-147) and controls. It was obvious that an animal with extruded viscera could not be a control, for there were no facilities to prevent cannibalization of these animals by other swine. As a result of this, the treatment group was overbalanced with animals more severely wounded, although in both groups the criteria of an intraperitoneal wound was adhered to. Again, unfortunately, selection could not be limited to the pretest criteria of an upper-abdominal or thoraco-abdominal wound, for there simply were not enough of these wounds identified.

Nineteen animals (versus 100 expected) were evacuated from the triage station to the resuscitation and anesthesia unit (Group 1, 11 animals) and to the Abdominal Wounds Control Station (Group 2, 8 animals).

The operative technique followed in the treated group was standardized. Careful clinical records were maintained on all treated animals to record their response to treatment. A sample clinical-record form is shown in Figure 3.1. Any animals dying in either Group 1 or Group 2 were carefully autopsied.

3.3.2 Controlled Wound Study. Because of the response of wounds to further trauma once the systemic response to irradiation has set in, as demonstrated in both the WRAIR and Reference 20 studies, a controlled wound study was planned in the animals subjected to significant levels of total-body irradiation (350 r ± 50) from Shot Priscilla. This was a wound of the shoulder, created in all animals by a single surgeon, and excising the infra-spinalis muscle to a predetermined depth (Figures 3.2, 3.3, and 3.4). In this report, it is also referred to as the standard shoulder wound (SSW).

An almost immediate postshot estimate of yield of the test device was obtained, and from this it was felt that the station that would have received 350 ± 50 r was Station 9. This was farther out than had been anticipated from pretest estimates, and the swine in this location were much smaller than those evaluated in pretest studies; thus, it was not possible to select 60 animals that would tolerate the anesthesia necessary to carry out the surgical program. Selected was a total of 49 animals (some weighing only 16 pounds) that had received little trauma other than irradiation. This, unfortunately, turned out to be only 84 rep, gamma plus neutron, from more reliable measurements.

These animals were divided into two groups:

Group 1, totalling 31 animals, received an SSW the day of exposure to the nuclear weapon. The wounds were closed; background studies had demonstrated that because of the habits of swine, it was impossible to obtain a clean, granulating wound ideal for secondary closure. However, to give a control granulating wound, 12 of the animals in Group 1 received, in addition to the SSW, a standard rump wound (SRW). When it was anticipated that there would be beginning maximal hematological response to irradiation, these wounds were to be re-excised and have secondary closure. (Because of the low level of total-body irradiation received, no significant hematological response was detected in the animals selected for the study.) The schedule for re-excision and secondary closure was as follows: (1) D + 4, 8 pigs (including 4 SRW); (2) D + 5, 7 pigs (including 2 SRW); and (3) D + 6, 11 pigs (including 3 SRW). The discrepancies in totals, 26 versus 31, is accounted for by the anesthesia death of five on the day the original wounds were created.

Group 2 had 18 animals, not 30, because experience with Group 1 indicated that the smallest animals, less than 18 pounds, did not tolerate the general anesthesia necessary for the surgical procedure. Group 2 received an SSW on D + 1. Randomized animals in this group had white-blood-cell counts at frequent enough intervals to demonstrate to observers that there was to be no significant hematological response. Accordingly, these animals had the SSW re-excised and closed on D + 14, a time when, from background studies, if they had had a hematological response to irradiation (drop in circulating white blood cells), it would be maximum.

A careful record of the clinical course of each animal was kept. All of the controlled wounds were followed at regular intervals. Notation was made of healing, wound color, exudate, odor, induration, local heat, and other pertinent factors. In addition to the clinical record, the wounds were followed by still photography. No attempt was made to follow healing histopathologically.

3.4 CLINICAL COURSE OF WOUNDED ANIMALS

Selected for this study were 324 animals; 123 were from Station 6, 122 were from Station 7, and 79 from Station 8. The distribution of wounded and burned in these groups is shown in Table 3.1.

At Station 6, the number of wounds on each animal ranged from 0 to 12. Most frequently they were from 0 to 3. The size of the wounds were 1 to 8 cm long and 0.5 to 3 cm deep. The average length of wounds was 2 cm, and the average depth was approximately 1 cm. The proportion of body surface burned in the Station 6 animals was rather a uniform distribution of from 0 to 50 percent.

At Station 7, the number of wounds per animal ranged from 0 to 8. Most wounded animals had 0 to 3 wounds recorded. The size and depth of wounds was similar to that of the Station 6 animals. As in the case of Station 6, the burns at Station 7 were uniformly distributed between 0 and 50 percent of the body area.

The number of wounds in Station 8 animals ranged from 0 to 7. Most frequently they were from 0 to 3. The most common wound was 2 cm long and 1 cm deep.

These animals were studied at intervals after irradiation for signs of inflammation in the wounds and burn. Appetite, activity, and presence or absence of diarrhea were recorded daily as an index of systemic response to whole-body radiation.

3.5 RESULTS

3.5.1 Surgical Wound Treatment. For the glass missile wound study, 11 animals were evacuated to the resuscitation unit for treatment (Table 3.2). As mentioned earlier, these animals were wounded more seriously than the control group, eight of the eleven having extruded abdominal viscera and two with sucking thoraco-abdominal wounds. The animals in the treatment group were from more-forward locations in six of the eleven instances and, as such, received considerably more irradiation, 1,034 rep versus 615 rep. Of the eleven animals reaching the resuscitation unit, four succumbed before they could be operated upon. Of the seven animals operated upon, all survived surgery, but the longest survival postoperatively was 100 hours. Six of the seven animals survived the recovery period. The one animal that did not survive the immediate recovery period had, at autopsy, a lacerated aorta at the site of anesthesia induction, with associated hemothorax, hemopericardium, and cardiac tamponade. In their short postoperative period, the remaining six animals demonstrated healing of the wounds but died the classical radiation death observed in other animals from the same locations.

The eight animals selected as controls (Table 3.3) had demonstrated penetrating abdominal wounds, and one had a thoraco-abdominal wound. However, none of these animals had extruded abdominal viscera, and none were from as far forward (Station 6) as were seven of the eleven animals of Group 1. Of these eight animals, three became permanent survivors; all wounds were healed by D+21. The earliest death in Group 2 was at H+151 hours—51 hours later than the longest survivor in Group 1.

For the controlled wound study, 49 animals had an SSW created and closed within 36 hours after exposure to Shot Priscilla. In addition, 12 of these animals had an SRW. Peripheral white blood counts done on the selected animals on D+1 and D+2 days demonstrated only a questionable lowering of circulating white blood cells; when repeated on D+5 and D+6 days, the counts demonstrated no significant radiation effect.

All of the original wounds healed uneventfully, without significant induration and little or no exudate at the time of re-excision (Figures 3.5 and 3.6). Those rump wounds that were left open were encrusted but dry, with minimal erythema and induration (Figure 3.7). Eight swine had re-excision of the SSW, four with SRW, on D+4. On D+5, seven swine (including two with SRW) and on D+6, eleven animals (including three with SRW) had re-excision and closure (Figure 3.8). The clinical course of these animals was uneventful. All the wounds healed uneventfully although some were broken open when the

animals rubbed or scratched themselves, even these gaping wounds did not manifest untoward erythema or induration and remained dry (Figures 3.9 through 3.11).

Of the eighteen animals which had re-excision on D+14, three were anesthetic deaths. The survivors had wounds that healed uneventfully, and there was no clinical difference in the course of the wound healing over those animals re-excised on D+4, 5, and 6. All wounds remained dry, with minimal induration and no excessive local reaction.

3.5.2 Clinical Course of Wounded Animals. In the animals from Station 6, the mortality was 100 percent at D+10 days; from Station 7, 97 percent at D+21 days; and from Station 8, 35 percent at D+21 days.

In Figures 3.12, 3.13, and 3.14 wounds, burns, and wounds plus burns are plotted against survival time, for those animals from Station 6. Figure 3.12 shows the inverse association between the degree of burn and length of survival time. In Figure 3.13, the inverse association between the number of wounds and survival time is not as apparent, however. On combining wounds and burns in Figure 3.14 by giving 0.5 point per wound and 0.5 point per 5-percent burn, there is a strong inverse association of this combined injury and survival time. Except for four animals that died within 6 hours after the time of recovery, there were no deaths for 46 hours; when deaths started occurring, at this time, they occurred at a regular rate for 10 days.

In the animals from Station 7, death did not become regular until 96 hours after exposure and continued for 14 days. Figures 3.15, 3.16, and 3.17 again show the inverse association between degree of burn and survival time. There is little suggestion here of any association between number of wounds and survival time in this group. The plotting of number of wounds showing inflammation against survival time suggested no association.

The number of burned animals dead at Station 8, as shown in Table 3.4, suggests an association again of burn and mortality. As shown in Table 3.5, there was no overall contribution by wounds to the mortality of these animals.

The average white blood count (WBC) on 26 burned animals of Station 8, D+7, was 10,000. On 30 unburned animals of the same group of the same day, the average WBC was 11,800. With the variation in figures in both groups between 3,500 and 18,000, it is not felt that this difference is significant.

Of the 89 wounded animals from Station 6, 76 developed slight induration about the wound. Exudate was slight in most cases. This mild inflammation subsided in 23 animals prior to death. Only one animal showed an increase to moderate inflammation. The animals of this group died of supralethal levels of radiation. At the time of death, there was no clinical difference in rate or extent of burn healing compared to those animals receiving sublethal levels of radiation.

From Station 7, 43 of the 74 wounded animals developed minor inflammation at the site of injury. It appeared on the first to the third day and subsided on the third to the ninth day. Two wounds developed small abscesses. Eleven of the 77 burned animals of this group survived long enough for observation of the healing process; six showed granulation beneath the eschar at D+7 to 11 days. Lighter burns were epithelialized by this time. Granulating surfaces and eschar both continued on parts of the more severe burns through D+19 days. In essence, these burns healed uneventfully.

From Station 8, 33 of 41 wounded animals developed inflammation: 15 started on D+1, 14 started on D+3, and in 4 the onset was observed on D+7. Eight subsided on D+7, 5 on D+11, and 14 by D+13. In most cases, this inflammation was slight to mild. In six animals, there was prolonged inflammation. Three of these showed major swelling and

local spreading of the infection. One animal showed a local swelling at the site of a small lower-abdominal injury, which was revealed at autopsy to be due to necrosis of herniated bowel.

Of the 29 burns in this group, 17 were completely epithelialized by D + 7 and 11 by D + 13; 1 showed a granulating surface beyond D + 13. No burn showed any sign of infection in any of the groups.

3.6 DISCUSSION AND CONCLUSIONS

3.6.1 Surgical Program. In the glass missile wound study, it is impossible to compare the treatment group (Group 1) with the control group (Group 2), because of the much more severe injuries and higher levels of irradiation in Group 1 than Group 2. There was no way that an animal with extruded abdominal viscera could be left in the control group. Those animals in Group 1 that survived surgery and the immediate recovery period had received such levels of total-body irradiation that their course was easily compared with that of other animals from the same location in other series; they died a similar type of death, that of irradiation. Anesthesia and surgery in the immediate post-exposure period appeared to be well tolerated by the swine, and the clinical course of the laparotomy wounds appeared to be uneventful in those animals who survived.

No conclusions can be reached from this study other than that, under the conditions of this experiment, any animal suffering severe missile wounds from glass will have received lethal doses of irradiation. However, in an actual situation, it would not be possible to define the levels of irradiation that the injured would have received, so each wounded individual will have to be managed according to his own injuries. As in the case of swine in this experiment, it may be found that innumerable man-hours have gone toward treating an injured patient, only to have him succumb in 3 to 4 days from irradiation.

In the controlled wound study, the levels of radiation received by the animals selected for this study were much less than had been planned. The dose delivered at Station 9 was only 84 rep, which failed to alter the post-exposure course of the animals. The original concept of wounding the animal immediately after exposure to radiation and comparing the course of this wound with one created after the systemic response to radiation had set in could not be carried out. At no time, in the animals selected, could a response to radiation be demonstrated. There was never a significant drop in circulating white blood cells. If the animals from Station 8 had been selected, having received 268 rep, there would have been a much better chance of proving a hypothesis.

One point demonstrated was that, in swine receiving 84 rep whole-body radiation, there is no difference in the course of wound healing, either in the initial wound or the wound challenged during the course of the response to this level of radiation.

3.6.2 Clinical Course of Wounded Animals. In animals wounded, or burned and wounded, the clinical healing of the wounds and burns appeared to be little influenced by whole-body irradiation. In those swine that received extensive burns plus supralethal levels of irradiation at Station 6, the burns were dry and grossly healing uneventfully at death. Wounds or wounds and burns that complicate whole-body irradiation significantly alter the post-exposure course of the animal. It appears that combined injury of the degree experienced by those swine at Stations 6 and 7 shortened survival time by as much as 30 percent when compared to the swine that irradiated only, during Shot Wilson.

TABLE 3.1 WEAPON-EFFECT ANALYSIS, STATIONS 6, 7, AND 8

	Stations		
	6	7	8
Total animals	123	122	79
Wounded	89	74	41
Burned, greater than 10 percent	85	77	28
Wounded and burned, greater than 10 percent	60	42	17
Uninjured	4	11	16

TABLE 3.2 GROUP 1, ABDOMINAL WOUNDS, TREATMENT

All animals suffered burns from 15 to 40 percent body-surface area. All burns healed uneventfully even though radiation-type death supervened.

Animal Number	Location	Radiation	Thermal	Wound	Course	Time of Death
		total rep	cal/cm²			
981	6	1,034	44	Extrusion bowel through flank wound.	Tolerated surgery well. Radiation death.	H+41
739	6	1,034	44	Extrusion small bowel through two anterior abdominal wounds.	Tolerated surgery well. Aspirated through tracheotomy tube and died.	H+9
537	6	1,034	44	Extrusion omentum through flank wound.	Tolerated surgery well. Radiation death.	H+89
671	6	1,034	44	Extrusion small bowel through right flank wound.	Tolerated surgery well. Aspirated through tracheotomy tube and died.	H+7
928	7	615	39	Extrusion small bowel through right flank wound.	Extensive bowel resection. Never recovered from anesthesia.	H+6
692	6	1,034	44	Sucking thoraco-abdominal wound. Lacerated stomach.	Tolerated surgery well. Died from lacerated aorta at site of anesthesia.	H+13
674	6	1,034	44	Penetrating abdominal wound through small laceration	Tolerated surgery well. Fifty percent burned. Radiation death.	H+100
112	6	1,034	44	Sucking thoraco-abdominal wound.	Died in resuscitation. Respiratory death.	—
382	7	615	39	Extruded small bowel through flank wound.	Death during induction of anesthesia.	—
425	6	1,034	44	Extruded viscera.	Could not resuscitate.	—
1,082	8	268	32	Extruded viscera.	Death during induction of anesthesia.	—

TABLE 3.3 GROUP 2, ABDOMINAL WOUNDS, CONTROLS

All animals suffered burns from 15 to 40 percent body-surface area. All burns healed uneventfully even though radiation-type death supervened.

Animal Number	Location	Radiation	Thermal	Wound	Course	Time of Death
		total rep	cal/cm²			
579	7	615	39	Penetrating abdominal wound.	Penetrating abdominal wound left flank. D+4 diminished activity and diarrhea. Radiation death.	H+160
613	7	615	39	Penetrating abdominal wound, left flank.	D+6 diminished activity, wounds healed. Radiation death.	H+239
657	7	615	39	Penetrating ventral abdominal wound. Fecal fistula.	Fistula spontaneously closed. D+4 activity diminished. Wounds dry.	H+180
658	7	615	39	Penetrating chest wound. Penetrating abdominal wound.	Diminished activity D+6, downhill with radiation death. Wounds healing.	H+151
917	7	615	39	Right thoraco-abdominal wound.	Wounds and extensive burn remained dry. Diminished activity D+6. Radiation death.	H+157
1,062	8	268	32	Penetrating abdominal wound, left flank.	Diminished activity D+7 to 10, then very active.	Permanent survivor
1,086	8	268	32	Penetrating thoraco-abdominal wound.	Remained active and eating well.	Permanent survivor
1,174	7	615	39	Penetrating abdominal wound, left flank.	Never any diarrhea. Because of broken bone in leg, didn't move about much	Permanent survivor

TABLE 3.4 MORTALITY, BURNED VERSUS NO BURN, STATION 8

Condition	Number of Animals		
	Living	Dead	Total
Burned	18	13	31
Not burned	36	12	48
Total	54	25	79

TABLE 3.5 MORTALITY, WOUNDED VERSUS NOT WOUNDED, STATION 8

Condition	Number of Animals		
	Living	Dead	Total
Wounded	30	11	41
Not wounded	24	14	38
Total	54	25	79

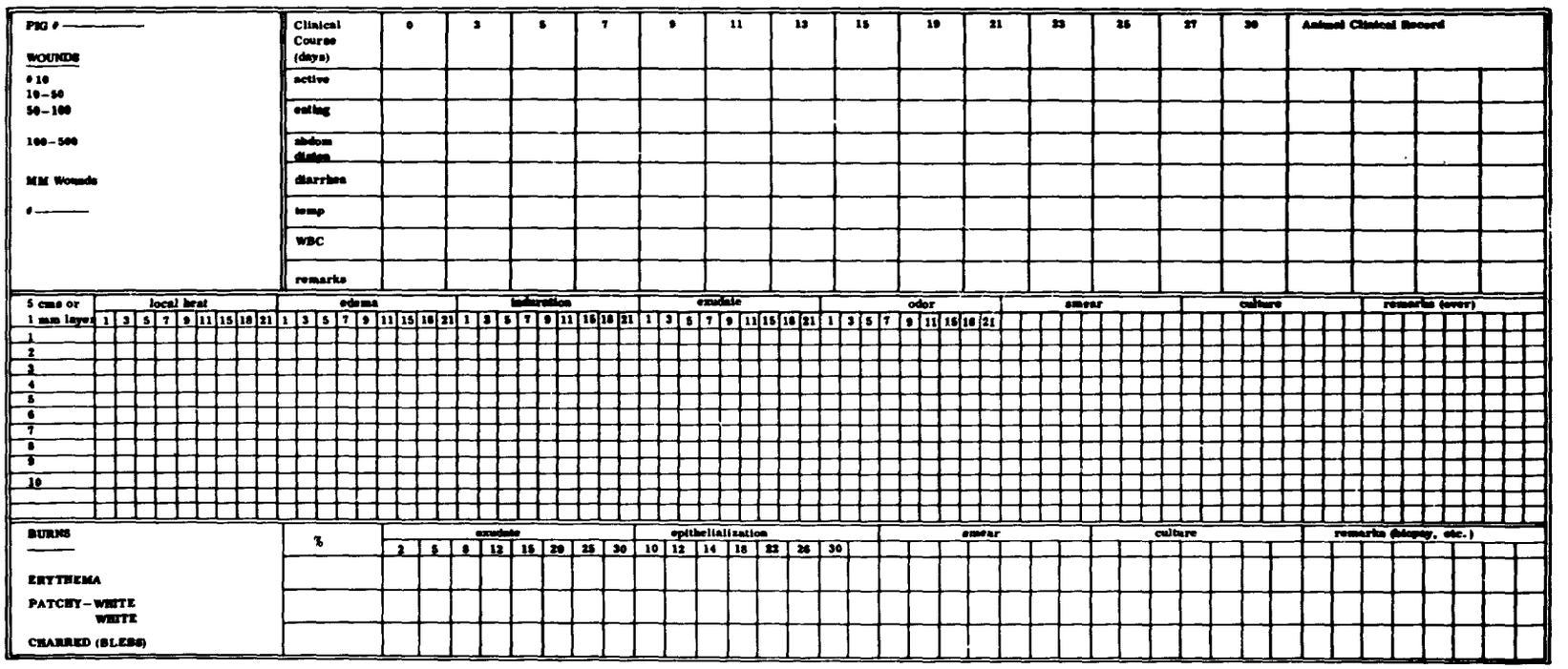


Figure 3.1 Clinical-record form.

Figure 3.2 Recently excised standard shoulder wound extending through the superficial layers of the infra-spinatus muscle.

Figure 3.3 Standard shoulder wound loosely closed.

Figure 3.4 Standard shoulder wound allowed to granulate as an open wound. This was subsequently revised and closed loosely as in Figure 3.3.

Figure 3.5 Standard shoulder wound, 2 days postoperative, demonstrating healing by primary intention.

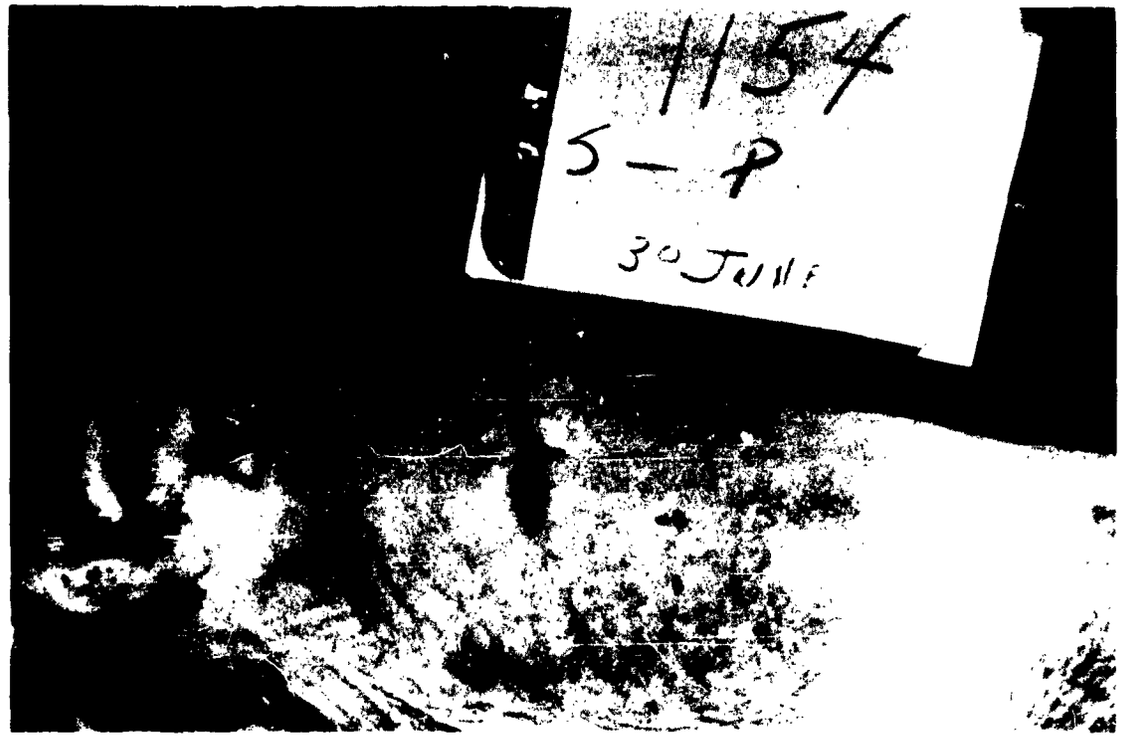


Figure 3.6 Standard shoulder wound for re-excision sixth postoperative day. Despite moderate separation of the edges, the wound is dry with minimal induration.

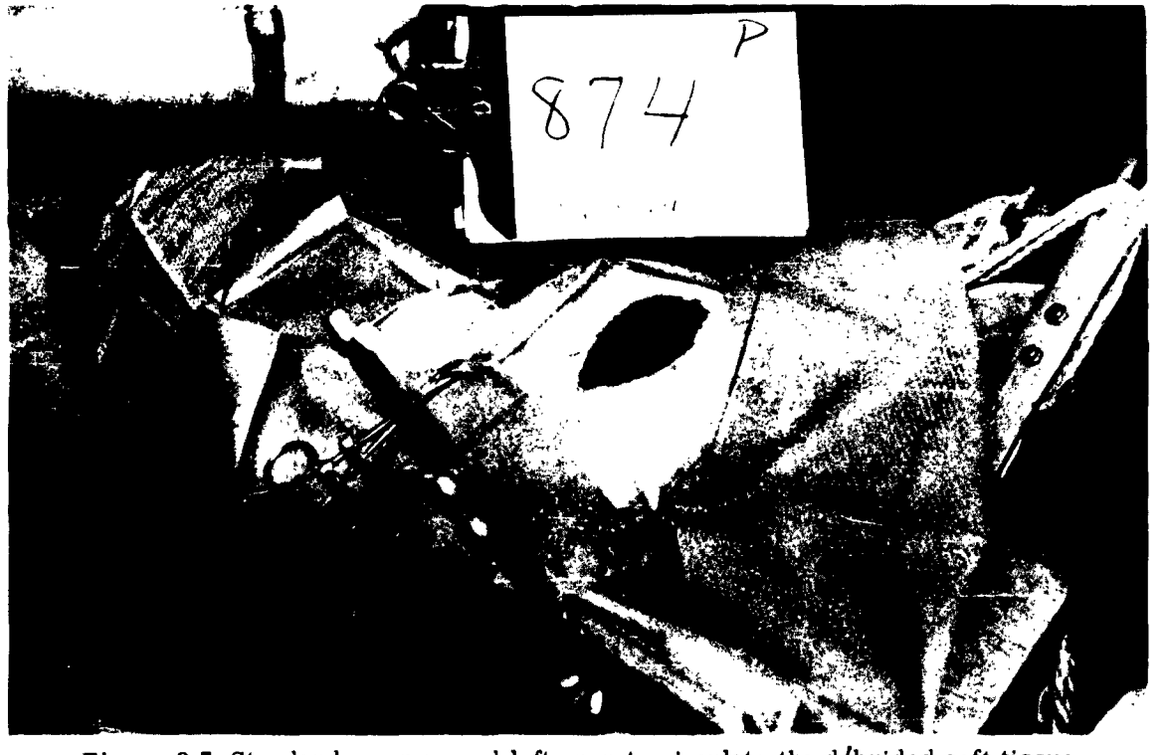


Figure 3.7 Standard rump wound left open to simulate the debrided soft tissue wound. Wound, though encrusted with debris, is dry and without induration.

Figure 3.8 Re-excised shoulder wound prior to closure. Healthy granulations have obliterated the surgical soft tissue defect.

Figure 3.9 Healing of re-excised wound, Specimen 851.

Figure 3.10 Healing of re-excised wound, Specimen 1161.

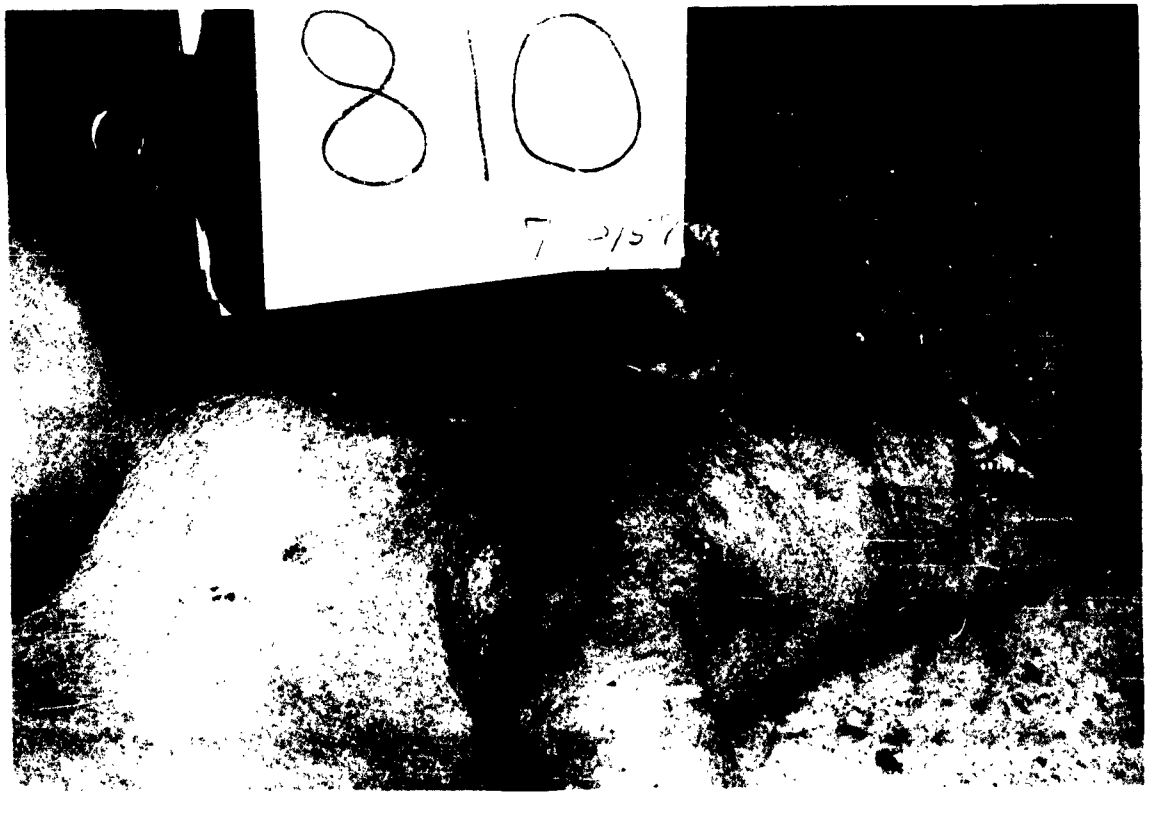


Figure 3.11 Healing of re-excised wound, Specimen 810.

Figure 3.10 Healing of re-excised wound, Specimen 1161.

Figure 3.11 Healing of re-excised wound, Specimen 810.

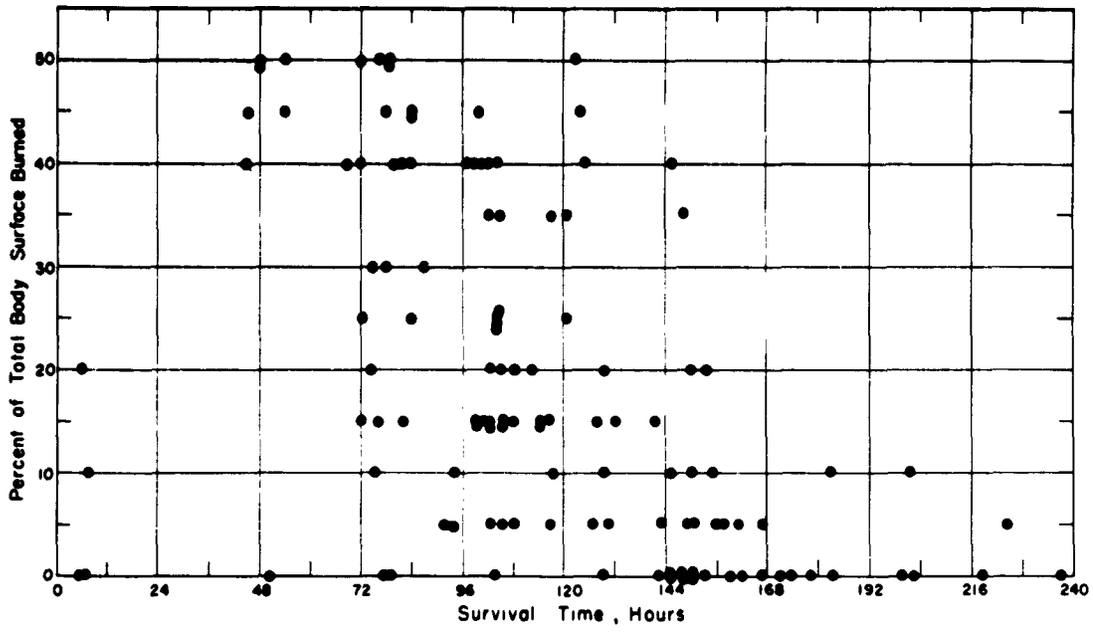


Figure 3.12 Extent of burn versus survival time, Station 6.

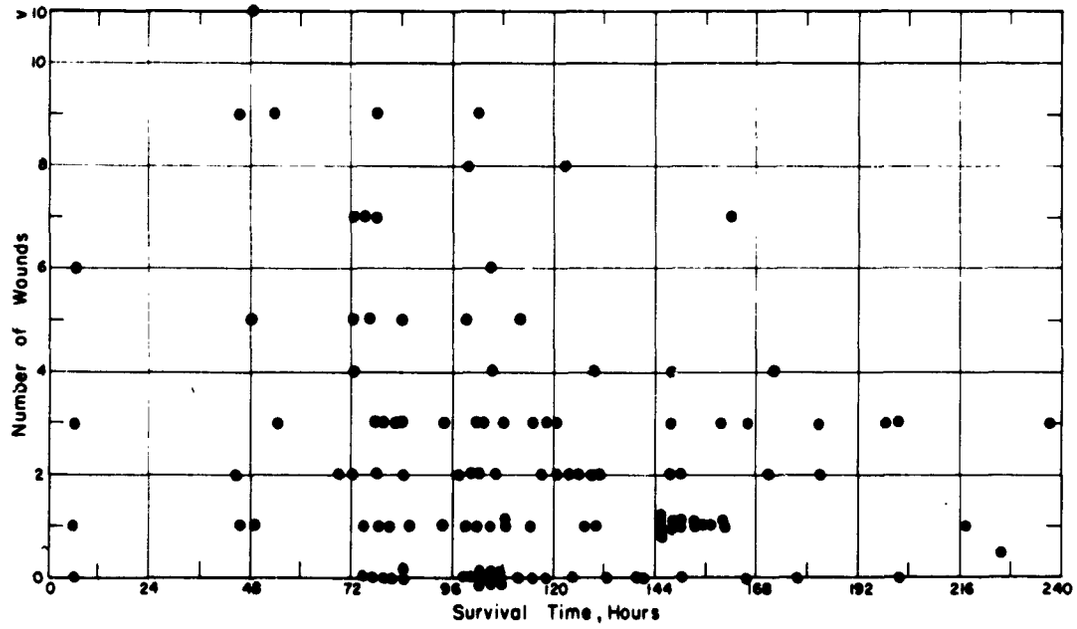


Figure 3.13 Number of wounds versus survival time, Station 6.

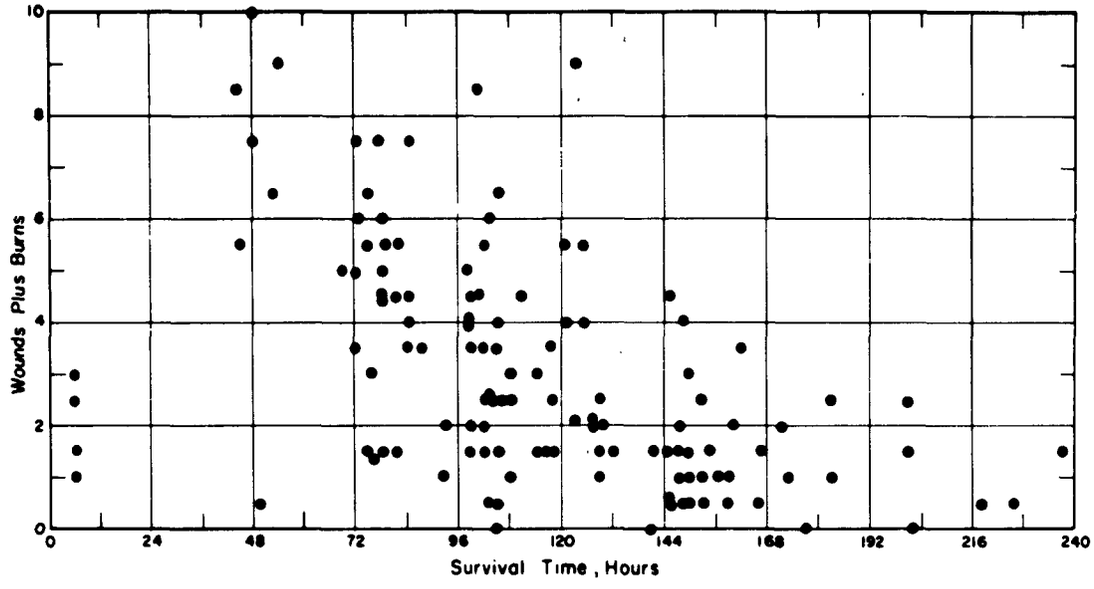


Figure 3.14 Combined wounds and burns versus survival time, Station 6.

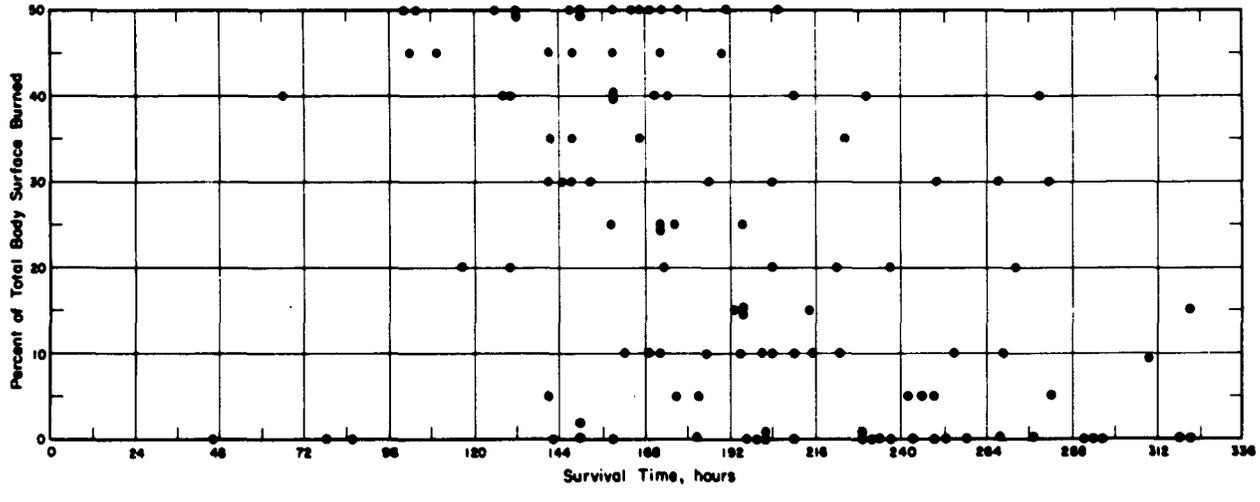


Figure 3.15 Extent of burn versus survival time, Station 7.

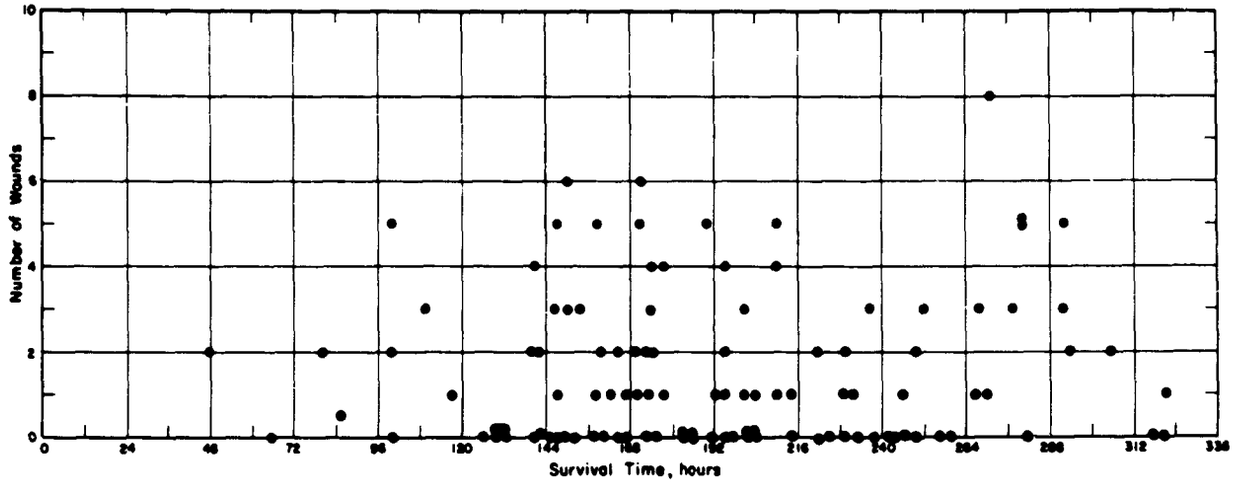


Figure 3.16 Number of wounds versus survival time, Station 7.

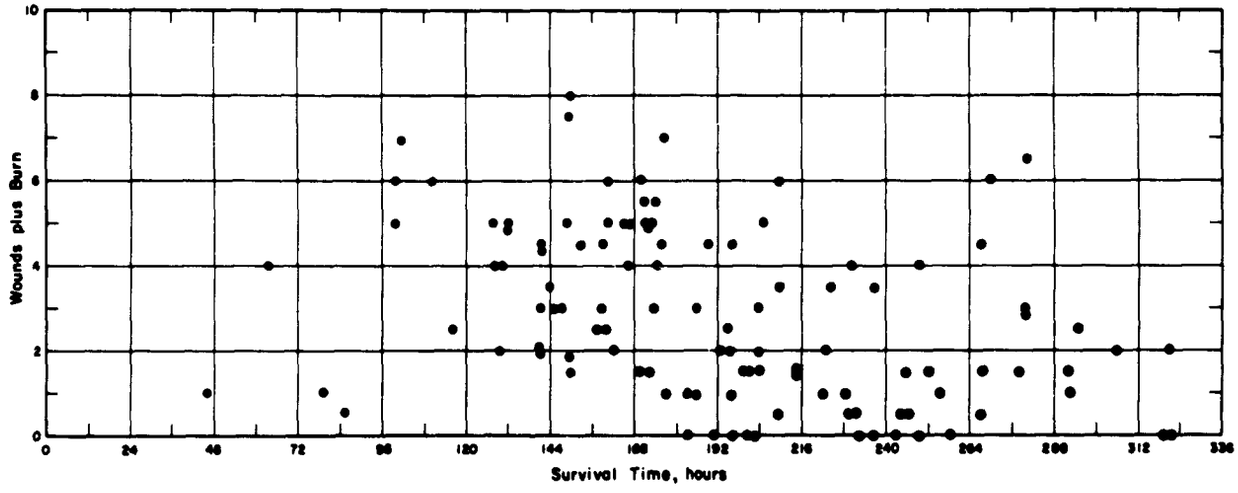


Figure 3.17 Combined wounds and burn versus survival time, Station 7.

Chapter 4

BACTERIOLOGY

4.1 OBJECTIVE

The occurrence of septicemia in irradiated mice has been well established. The reduction in mortality in these animals by streptomycin therapy has indicated the significance of these invading bacteria. Of a group of animals exposed to the effects of a nuclear device, which would dispense ionizing irradiation, burns, and lacerations, it is of interest to know to what degree bacteria invade the tissues of the animals. At what time after injury do the microorganisms invade? What is the nature of these bacteria? What is their source?. What is their relation to the host?

The objective of this part of the experiment was to determine a bacteriological history of the swine, from which hypotheses could be formed for use in future field tests of nuclear devices.

4.2 PRELIMINARY STUDIES

A prior trial on cultures from skin, nose, and alimentary canal of three normal pigs yielded the data presented in Table 4.1. Six groups of organisms were found in countable numbers. Streptococcus faecalis and Clostridium species were found at all sites. Beta-hemolytic Streptococci were isolated from the nose and jejunum. Staphylococci were prominent in the jejunum and on the skin. Corynebacteria were found in the stomach, cecum, and skin. Coliforms were found in the large bowel and on the skin.

Table 4.2 shows the degree of bacterial invasion of the blood in four groups of animals. Group 1 comprised three blood cultures on a pig without wound and without irradiation. Group 2 was composed of three animals with wound and without irradiation. Group 3 animals were given total-body irradiation to different degrees but had no wounds. Group 4 animals had wounds and 500 r of total-body irradiation. Blood cultures were not consistently positive on cultures subsequent to the first positive culture. Although occasionally different bacteria appeared, generally the subsequent positive cultures were qualitatively consistent. Two to ten cultures were taken on each animal. The average number of cultures was five. The frequency of positive cultures increased with radiation dosage. The prominent bacteria in these cultures were Staphylococci, Beta-hemolytic Streptococci, and Pasteurella multocida.

The morbidity response of swine to contaminated soft tissue wounds was evaluated. In two animals, 9 cm^2 of skin was removed on the posterolateral aspect of the thigh and the underlying muscle deeply incised in grid fashion, crushed, and contaminated with dirt from a Washington street. Wounds were clean and healing in 8 to 12 days. When no skin was removed but the muscle similarly traumatized and contaminated through a simple incision, 6 of 21 pigs (30 to 80 pounds) died. In weanling pigs (20 to 29 pounds) this procedure resulted in death in five out of nine animals so treated. One pig of three (50

pounds) whose wounds were contaminated with NTS soil died. Clostridium novyi appeared to be the most pathogenic microorganisms contaminating the wounds of swine. All swine dying of wound infection demonstrated the characteristic edema produced by this microbe, and it was regularly isolated from the contaminated experimental wounds of these animals and from the adjacent lymph nodes at necropsy. A fecal study of 31 animals was made in the field in pigs selected at random from the herd on D−13 days. The specimens were taken on swabs and processed for shipment in the same manner as those for the postblast studies. The preblast studies of fecal bacteria on these pigs are presented quantitatively in Table 4.3. These observations show 91 percent of the pigs had aerobic Gram-positive bacteria in the feces at 1×10^6 per gram, and for coliform bacteria the mean count was approximately 5 logs. Table 4.3 indicates 97 percent of the animals showed coliform bacteria in the feces. Among the Gram-positive aerobic bacteria, the Streptococcus faecalis appeared most frequently among the specimens cultured. The third ranked microorganism in order of frequency of appearance in these cultures was the Staphylococcus albus. Nonlactose fermenting Gram-negative rods appeared in 13 percent of the cultures. These microorganisms were not further identified.

At necropsy of animals dying from the herd prior to blast, cultures were taken on three pigs showing hemorrhage in the bowel, and hemorrhagic mesenteric lymphnodes showed Salmonella cholerasuis on each.

4.3 PROCEDURE

Animals selected for study were those so placed that they received irradiation, significant number of wounds, and significant burns. The 324 animals comprising this study group were 123 from Station 6, 122 from Station 7, and 79 from Station 8, Shot Priscilla, described in the wound-healing observations of Chapter 3. During the 21-day observation period following the detonation, 1,523 specimens were processed.

On D+4 and D+6 days, blood cultures were taken from the superior vena cava of the swine, using 22-gage, 3-inch needles. The skin of the suprasternal area was cleansed with soap, shaved, and treated with 4 percent iodine prior to puncture. Two ml of blood was taken in a heparinized syringe and delivered to a sterile screw-capped tube in which it was shell-frozen within an hour and stored in dry ice for shipment.

Wound cultures were taken daily for the first 6 days and at subsequent intervals as long as any exudate appeared in the wound. These cultures were taken by inserting standard machine-rolled swabs deep into the wound until the swab was saturated. The cotton tip was broken off into a 4-ml screw-capped vial containing 1 ml of 1 percent gelatin buffered with phosphate at pH7. The contents were shaken and shell-frozen within an hour. Specimens of feces on D+3, 6, and 13 days after blast were taken similarly on swabs. On D+3, fecal cultures were taken from 20 pigs of Station 10 that received minimal irradiation. These served as controls.

Cultures were taken on animals necropsied within 2 hours after death. Heart blood was taken by syringe and needle through the seared heart surface. Cultures of the various tissue specimens were taken with sterile swabs, after searing the tissue surface and puncturing the center of the seared area with flamed scalpel. The swabs were pushed into the tissue and rotated until some tissue juice had soaked into the swabs. This material was processed in the buffered gelatin vials similar to the wound cultures. Ten healthy pigs that received minimal irradiation at Station 11 were sacrificed by electrocution on D+21 days and allowed to lie dead for 1 hour prior to necropsy and complete bacteriological cultures. These animals represented controls for the necropsy cultures.

All specimens were shipped in dry ice by air to the Bacteriology Section, Department of Experimental Surgery, WRAIR.

The following media were employed with each of the specimens. For blood cultures from living animals and at necropsy: 0.1 ml in blood agar base pour plate, aerobic; 0.1 ml in blood agar base pour plate, anaerobic; and 1 ml in 10 ml cooked meat medium. For wound cultures (violet red bile for counting gram-negative bacteria): blood azide for counting Gram-positive aerobic bacteria, blood azide lecithin anaerobically for counting Clostridia, and cooked meat medium. For fecal cultures, the media were the same as for wounds except that the aerobic blood medium did not contain sodium azide. For necropsy cultures: blood agar, aerobic; blood agar, anaerobic; blood azide, anaerobic; and cooked meat medium.

The rapid slide identification of pathogenic bacteria in mixed culture by fluorescent-labeled antisera was studied. Immune rabbit sera were prepared for Clostridium perfringens, Clostridium novyi, Clostridium tetani, and Clostridium bifermentans and were conjugated with fluoroscein by the method outlined in Reference 21. The labeled antisera were tested for specificity of staining reaction with 45 species of commonly appearing aerobic bacteria and against 50 strains of the genus Clostridia. No cross reactions were observed. Smears of wound exudate from rabbits, containing a heterogeneous mixture of aerobic and anaerobic bacteria, were stained to determine the influence of aerobic, purulent material on the reactivity of the staining process. No nonspecific reactions were observed.

4.4 RESULTS

4.4.1 Fecal Cultures. The bulk of the fecal specimens were taken on D + 3 and D + 6 days from pigs from Stations 6 and 7. Specimens from pigs from Station 8 were also taken on D + 13 days to observe the frequency of occurrence of Salmonella, because diarrhea had increased in that group at that time. In Table 4.5 it can be seen that 5 percent or less of animals showed Salmonella on D + 6 days. By D + 13 days the major group of survivors were from Station 8, and fecal cultures on these animals revealed no increase in the frequency of Salmonella, i.e., 2 percent.

The frequency by which various groups of microorganisms appeared among the fecal specimens is presented in Tables 4.4 and 4.5. The changes noted from the control studies of Table 4.3 are that the coliforms appear less frequently among the animals of Stations 6, 7, and 8 on D + 3 days. The animals of Station 10 that received much less exposure to the detonation showed a frequency of coliforms approaching that of the preshot observation. The frequency of Streptococcus faecalis is almost the same in Tables 4.3 through 4.5. The Staphylococci shows a marked increase in frequency for Stations 6 and 7 on D + 3 but have returned to the control level on D + 6. Beta-hemolytic Streptococci appeared in the cultures only in low frequency of 15 percent (average) on D + 3 and 9 percent (average) on D + 6.

The quantitative data on the fecal specimens is presented in Table 4.6. Because no differences were seen in the specimens from Stations 6, 7, and 8, this data is combined and shows that on D + 3 and D + 6 the coliform bacteria are apparently depressed in the feces below the numbers seen in the preblast specimens, the mean number being about 1,000. The total bacteria as observed on blood agar plates show that the total count, comprised largely of Gram-positive cocci, is reduced but slightly from the preblast level.

4.4.2 Wound Bacteriology. Approximately 250 wound specimens were studied of which 235 contained from 1 to 8 bacterial species. A total of 14 bacterial species were found in these specimens. Table 4.7 lists the species most frequently identified. It is immediately apparent that the qualitative flora of these wounds were predominantly Gram-positive organisms, mostly cocci, regardless of the station of the pig at the time of wounding. It should be noted that Pasteurella multocida, a natural pathogen for swine and one that was found in a number of blood and necropsy cultures, was never isolated from wound cultures. Another item of interest is that the organisms associated with gas gangrene were frequently found, but their presence in the wounds did not result in appreciable infection. Staphylococcus albus and Beta-hemolytic Streptococci appeared most frequently in these cultures.

Quantitative studies presented in Tables 4.8, 4.9, and 4.10 show that the bacterial counts in the wound fall off after D + 2.

Quantitatively, as well as qualitatively, the great majority of the organisms in these wounds were cocci. While Clostridia — mostly Clostridium perfringens — were frequently found in the wounds, they were invariably present in small numbers.

When the quantitative studies are evaluated in terms of stations, there are no significant differences on the first three days for Stations 6, 7, and 8. There were so few samples from animals from Station 6 after D + 3 that comparisons on samples D + 5 or more days are confined to Station 7 and 8. Such comparisons show that the bacterial counts of these animals from Station 7 tended to be greater than those from Station 8, a finding in parallel to the degree of wound exudate in the two groups.

The use of the fluorescent antibody technique for determining Clostridia in smears showed that the frequency with which these organisms appeared in these smears was low. The range was one organism per five to ten high-dry fields. No specimen was considered positive unless at least five organisms were observed in that portion of the smear studied. Of the 804 smears examined, 14 had at least three organisms per high-power field. Nine of these smears showed Clostridium perfringens; four, Clostridium novyi; and one, Clostridium bifermentans.

Table 4.11 lists the results of a study comparing the conventional cultural technique for detection of Clostridia with the fluorescent-antibody technique. The results for the 135 cultures indicate that the lack of correlation between the techniques precludes dependence upon a fluorescent-antibody technique, for the evaluation of direct wound smears. Further study using known strains of diversified origin has demonstrated that a wide heterogenicity of antigenic factors exists among this group of organisms, which would require preparation of a complex polyvalent serum for each species.

4.4.3 Blood Cultures. Of 271 blood cultures taken D + 4 and D + 6, 45 percent were positive. In Table 4.12 it can be seen that the frequency of positive cultures for Station 6 remained high, i.e., 48 percent and 52 percent. Among the animals from Station 8, the frequency of positive cultures increased in the period from D + 4 to D + 6. Of the few blood cultures taken from animals from Station 8, relatively few were positive. For Station 6, 39 percent of positive cultures showed two or more different microorganisms. For Station 7, the frequency of positive cultures showing multiple species was 23 percent.

The microorganism most common in these cultures was Staphylococcus albus. Pasteurella multocida, Beta-hymolytic Streptococci, and Corynebacteria appeared in that order of frequency.

4.4.4 Necropsy Cultures. Results of cultures of heart blood at necropsy are shown in Table 4.13. These results are arranged in order of survival time, because it was observed that the changes in occurrence of bacteria are more consistent with survival time than with station of animals. (The increasing survival times for animals from Stations 6, 7, and 8 are shown in Table 7.11.) Of the blood cultures at necropsy 56 percent were positive, and 31 percent of the positives were of multiple species. As seen in the blood cultures taken prior to death, the necropsy blood cultures show that the Staphylococcus albus, Beta-hemolytic Streptococci, and Pasteurella multocida to occur most frequently. The frequencies of microorganisms shown from 0 to 3 days are not highly significant because of the low number of samples. The Staphylococci occurred most in the blood of animals dying during the first 9 days after the blast. The Beta-hemolytic Streptococci appeared almost as frequently as the Staphylococcus albus during the period up to D+6. Pasteurella multocida appeared at a regular rate after D+4, for an overall frequency of 13.8 percent in these cultures. Salmonella appeared in only 2 percent of cultures.

The necropsy cultures of the spleen (Table 4.14) reflect a similar pattern of occurrence of microorganisms to that seen in the necropsy blood cultures with the difference of the relative increase in frequency of Streptococcus faecalis and coliform organisms. Pasteurella multocida did not appear in the spleen cultures. The lung cultures (Table 4.15) were closely similar to the spleen cultures. Again Streptococcus faecalis and coliform organisms were second and third in order of frequency. Pasteurella multocida did appear in some of the lung cultures.

Tables 4.16 and 4.17 compare the frequencies of microbial species appearing in the mediastinal and mesenteric nodes. These follow generally the pattern of the other necropsy cultures; however, the major difference between the microorganisms appearing in the mesenteric node and the mediastinal node was the diminished frequency of Beta-hemolytic Streptococci in the mesenteric node.

Table 4.18 shows the frequency of single kinds of microorganisms appearing from different sites of culture on the same animal. Several interesting points appear in this comparison. If the relation of the fecal cultures to the necropsy and blood cultures is compared to the relation of wound cultures to the necropsy and blood cultures, a similarity is seen in the case of Staphylococcus albus, i.e., feces necropsy 29 percent, wound necropsy 30 percent. Similarly for Streptococcus faecalis the feces necropsy frequency is 20 percent and wound necropsy is 25 percent. For the coliforms, both are 14 percent. Similarly the frequencies of these organisms in feces blood and wound blood cultures results are approximately in the same range. However, the Beta-hemolytic Streptococci in wound necropsy cultures were 16 percent whereas occurrence in feces necropsy cultures was 2 percent. This difference was borne out when comparing wound blood cultures, 8 percent, and feces blood cultures, 1 percent.

On the last day of observations, D+21, all cultures of blood and organs taken from ten pigs of Station 11 sacrificed as controls were negative for microorganisms.

4.5 DISCUSSION

The mortality from wound infections that had been observed in the preliminary studies did not occur. This was due to the lack of severe muscle damage in the wounds. The pig is more than three times as resistant to clostridial wound infection than man, and the exposure to the nuclear detonation did not appreciably diminish this resistance.

A prominent feature of the results of bacterial culture of these animals is that certain microorganisms appeared relatively frequently in the blood cultures prior to death, and at necropsy, which were not characteristic of the fecal cultures. This observation is in contrast to the general impression that the bacteriemia of irradiation sickness is an invasion by microorganisms from the bowel. The particular species cited are the Beta-hemolytic Streptococci and Pasteurella multocida. Although the Beta-hemolytic Streptococci were found in the jejunum in studies of control animals prior to the test and in 4 percent to 19 percent of fecal cultures, these microorganisms appeared in the mesenteric lymph nodes only one-fourth as frequently as in the mediastinal nodes. The association of finding this organism in the feces and necropsy cultures of the same animal was only one-eighth as high as the association of finding this organism in the wound and necropsy cultures on the same animal. These observations indicate that the Beta-hemolytic Streptococci did not invade from the bowel; consequently, there is the question of whether the Beta-hemolytic Streptococci invaded the animals from the sites of the wounds where these organisms appeared with high frequency. This point might be checked by looking at the frequency of appearance of Beta-hemolytic Streptococci in the necropsy blood cultures of Station 8 animals where the wounds were small and less frequent. In 15 such cultures, Beta-hemolytic Streptococci were in four, whereas Staphylococcus albus appeared in three, Streptococcus faecalis in one, and coliforms in none. Apparently the Beta-hemolytic Streptococci occurred as often in the less frequently wounded animals from Station 8. If the group of animals dying in Station 8 with Beta-hemolytic Streptococci is compared to those dying with other bacteria in the blood, and with those dying bacteria free, there is seen to be no difference in the number of wounds or the degree of burns in each group. Thus, no relation can be established between the wounds and appearance of Beta-Streptococci in the cultures. Because the Beta-hemolytic Streptococci were one of the predominant organisms in the nose cultures of the preliminary swine studies, and this microorganism frequently invaded the blood of irradiated nonwounded pretest animals (along with a number of reports of Beta-hemolytic Streptococcal infections in the cervical lymph nodes of swine), it can be concluded that these animals were invaded by organisms from the upper respiratory tract.

The Pasteurella multocida were not found in the wounds and were observed very rarely in the feces. To reconcile how this agent became one of the more common microorganisms appearing in the blood cultures taken both before and after death, it is necessary to review the experience of the pathologists in this study. This is an agent which produces a characteristic interstitial pneumonia in swine and a disease known as hemorrhagic septicemia. Twenty animals died with pathological manifestations of this disease during the 30 days prior to Shot Priscilla. During 5 days following hog cholera vaccination and cold weather (D−30), this disease could be recognized in ten of the pigs. However, the frequency of death from this disease diminished so that the other 10 animals died of this disease over a period of 25 days prior to the detonation. In necropsies of animals after the blast, the lesions characteristic of Pasteurella multocida infections appeared to be more extensive. It is felt that the 13 percent positive blood cultures for Pasteurella multocida are, in part, manifestations of extensions of this disease from the lung. The low frequency of this organism in lung cultures when compared to blood cultures is best explained by the larger samples of material which were taken for the blood cultures. This also indicates that microorganisms invade the irradiated animals from locations other than the gastrointestinal tract. The Beta-hemolytic Streptococci and Pasteurella multocida have both been observed as agents residing in the tissues of swine in either cervical adenitis or interstitial pneumonia in a state of limited invasiveness.

The concept engendered by these observations is that in these animals exposed to the effects of this nuclear detonation, and its ionizing radiation, there was a compromise of the barriers to invasion by these agents.

Other pathogenic organisms, the Salmonella, were present in the herd as marked by necropsy findings in six sporadic deaths during the 30 days prior to D day. Bacterial cultures from three of these cases confirmed the diagnosis by isolation of Salmonella cholera suis. Excluding the 10 animals dying in the early outbreak of hemorrhagic septicemia following the hog cholera vaccination, the number of animals dying from Salmonellosis in this preshot period was approximately half the number dying from hemorrhagic septicemia of Pasteurella multocida. It is estimated that 0.5 percent of the herd of swine died of Salmonellosis during the preblast period. During the postshot observation period, these organisms were observed in less than 5 percent of the cultures from the animals from Station 6 and 8. The number of animals showing Salmonella in the feces did not increase. The number of animals showing Salmonella in blood at necropsy were 2.1 percent of all animals having necropsy blood cultures. The pathological studies would not indicate that more animals than this had Salmonellosis. Calculating from this figure, the Salmonellosis rate for the animals in Stations 6, 7, and 8 during the postshot observation period is 0.6 percent, or approximately the same as the calculated preshot rate.

Speculation might be generated to explain the fact that Salmonellosis did not occur in these groups of animals, because Salmonellosis is a human disease to be considered in postdisaster conditions. During shipment, these animals did not suffer types of stress that produce Salmonellosis. These animals were not crowded, they were offered adequate food and water, and they had sufficient opportunities for rest. The factors present in the herd which might have influenced the onset of intestinal infection were: (1) some influence which promoted diarrhea in about one-quarter to one-third of the population, and (2) the radiation effect which suppressed the white blood cell count in approximately two-thirds of these animals. No serum was taken to measure the antibody levels against these organisms or to follow the influence of the radiation upon them. It is known that, in some species, ionizing radiation will suppress temporarily properdin levels, but it is not expected that this level of ionizing radiation would influence the level of preformed agglutinins. The fact remains that, in this group of animals exposed to a nuclear device with Salmonella present in the herd, an outbreak of Salmonellosis did not occur.

This survey of the bacteriology of swine following exposure to a nuclear detonation has suggested this principle: the effects of the detonation lead to the invasion of those microorganisms that are held in restraint largely by phagocytic cellular elements and have no primary influence on pathogens that are controlled largely by humoral antibody mechanisms. If such a principle could be established in experimental animals, it would be useful in predicting the relations of man and his microbes following exposure to nuclear detonations. The bacterial invasion of the blood of the swine exposed to the nuclear detonation is so similar to that of swine in the laboratory receiving total-body irradiation that laboratory studies can be expected to provide information directly applicable to the exposure to nuclear detonations.

The method for processing the cultures was generally well suited to this type of survey. The most sensitive cultures taken in this system were the blood cultures. The swab specimens were excellent for the wound and fecal cultures where large populations of bacteria were examined. The cultures of lung, lymph nodes, and spleen might have been more revealing had sections of tissue been taken for culture. Such a method would have been more cumbersome and might have imposed a greater risk of counting

contaminants. The method as used allowed the processing of large numbers of cultures in the field for culture in an established laboratory more than 2,000 miles distant. Such a method would be suitable for a bacterial survey of wounds in the field in combat operations.

4.6 SUMMARY AND CONCLUSIONS

This study was not an experiment designed to test a particular hypothesis, rather it was an observation of general bacteriological events in a group of animals exposed to a nuclear detonation. It showed that the wounds were highly populated by a polymicrobic flora. Although pathogenic Clostridia were present in many of the wounds, disease did not result, because tissue did not receive a critical type of damage. The bacterial flora in the wounds diminished after the third day, paralleling the diminution of exudate. Minor depression in the general coliform counts in the feces were observed on D + 3 but were normal by D + 13; this cannot be attributed to the nuclear detonation. Salmonellosis was sporadic and did not increase in incidence in the post-detonation period. Staphylococcus albus, Beta-hemolytic Streptococci and Pasteurella multocida were the most frequent invading organisms. These organisms originated from sites other than the gastrointestinal tract. This latter is a new experience in studying the response of experimental animals to nuclear detonations.

TABLE 4.1 BACTERIAL FLORA OF NORMAL SWINE

Source of Specimen	Range of Bacterial Counts	Streptococcus Faecalis	Clostridium Species	Beta-hemolytic Streptococcus	Micrococcus Pyogenes Species	Corynebacterium Species	Coliforms
Nose	1.4×10^4 to 4.8×10^5	x	x	x			
Stomach	1.0×10^2 to 2.5×10^5	x	x			x	
Jejunum	2.5×10^4 to 1.4×10^6	x	x	x	x		
Cecum	2.9×10^6 to 2.6×10^7	x	x			x	x
Lower colon	10^4 to 10^7	x	x				x
Skin*	10^4	x	x		x	x	x

* Included were back, belly, lower leg, and thigh.

TABLE 4.2 BLOOD CULTURE RESULTS ON LABORATORY SWINE IN PRELIMINARY STUDIES

Group	Wounded	Total-body Irradiation	Number of Animals Tested	Number of Animals Showing All Negative Cultures	Blood Cultures			Bacteria Isolated (Percent of Total Cultures)
					Total	Positive	Negative	
		r						
1	–	0	1	1	3	0	3	None
2	+	0	3	2	11	2	9	Staphylococci 18 pct Beta-hemolytic Streptococci 9 pct Pasteurella Multocida 9 pct
3	–	200	5	1	26	10	16	Staphylococci 30 pct Listeria 12 pct Beta-hemolytic Streptococci 12 pct
	–	400	5	2	18	9	9	Staphylococci 24 pct Listeria 6 pct Beta-hemolytic Streptococci 11 pct
	–	500	4	1	17	9	8	Staphylococci 33 pct Beta-hemolytic Streptococci 12 pct Pasteurella Multocida 6 pct
	–	800	4	1	9	6	3	Staphylococci 44 pct Pasteurella Multocida 33 pct Listeria 22 pct Streptococci 22 pct
4	+	500	18	0	106	52	54	Beta-hemolytic Streptococci 16 pct Staphylococci 16 pct Pasteurella Multocida 13 pct E. Coli 1 pct

TABLE 4.3 QUALITATIVE STUDIES OF PREBLAST FECAL CULTURES OF SWINE

Expressed to nearest percent of animals with each organism.

Number of Animals	Staphylococcus Albus	Beta-hemolytic Streptococcus	Diphtheroids	Clostridium	Streptococcus Faecalis	Coliforms	Non-lactose Fermenting Gram-negative Rods
31	68	0	3	6	84	97	13

TABLE 4.4 BACTERIA FOUND IN SWINE FECES ON D+3 DAYS

Expressed to nearest percent of total cultures studied.

Station	Total Cultures Studied	Micrococcus Pyogenes Var Albus	Micrococcus Pyogenes Var Aureus	Beta-hemolytic Streptococcus	Corynebacterium Species	Clostridium Species	Streptococcus Faecalis	Coliforms	Pasteurella Multocida	Salmonella Species	Bacillus Species
6	83	90	77	16	0	83	93	74	0	4	18
7	104	93	73	9	5	62	92	51	0	0	28
8	78	73	41	19	3	51	97	77	0	1	35
10	20	80	55	15	0	100	95	85	0	0	35

TABLE 4.5 BACTERIA FOUND IN SWINE FECES ON D+6 DAYS

Expressed to nearest percent of total cultures studied.

Station	Total Cultures Studied	Micrococcus Pyogenes Var Albus	Micrococcus Pyogenes Var Aureus	Beta-hemolytic Streptococcus	Corynebacterium Species	Clostridium Species	Streptococcus Faecalis	Coliforms	Pasteurella Multocida	Salmonella Species	Bacillus Species
6	21	62	29	14	0	33	86	91	0	5	19
7	45	49	20	4	2	11	91	78	2	0	18

TABLE 4.6 QUANTITATIVE BACTERIOLOGY OF FECAL SPECIMENS

Percent of cultures for each log value.

	Number Specimens	Log No. of Bacteria/Gram Wet Feces					
		<3	3	4	5	6	>6
Preblast							
Coliforms	31	3	3	16	42	32	3
Total aerobic bacteria	31	3	0	0	6	65	26
Stations 6, 7, 8 (combined)							
Coliforms, D+3	195	46	27	16	6	5	0
Coliforms, D+6	103	45	20	19	9	7	0
Total aerobic bacteria, D+3	165	2	2	8	22	48	18
Total aerobic bacteria, D+6	68	4	0	15	38	39	4
Station 10							
Coliforms, D+3	20	35	5	15	35	10	0
Total aerobic bacteria, D+3	20	0	0	0	20	40	40

TABLE 4.7 BACTERIA MOST FREQUENTLY ISOLATED FROM WOUNDS OF SWINE

Expressed to nearest percent of total positive cultures.

Location and Sample Time	Positive Cultures	Micrococcus Pyogenes Var Albus	Beta-hemolytic Streptococcus	Micrococcus Pyogenes Var Aureus	Coliforms	Streptococcus Faecalis	Alpha-hemolytic Streptococcus	Clostridium Species	Proteus Vulgaris
Station 6									
D+1	44	82	75	75	73	66	55	30	18
D+2	23	91	91	87	78	74	83	48	22
D+3	11	82	91	64	63	64	91	46	9
D+5*	3	67	0	33	67	100	67	33	0
Station 7									
D+1	36	86	97	50	72	64	78	26	8
D+2	22	96	96	50	68	55	82	46	23
D+3	15	100	87	27	33	47	80	27	0
D+5*	9	100	33	0	33	44	78	22	0
Station 8									
D+1	32	75	91	75	66	66	56	13	3
D+2	4	100	100	100	75	0	75	25	0
D+3	13	85	92	62	39	39	92	23	0
D+5*	23	22	96	4	17	13	74	9	0

* And later.

TABLE 4.8 COLIFORM BACTERIA DETECTED IN WOUNDS OF SWINE

Expressed to nearest percent of total cultures taken on given days.

Location and Sample Time	Total Cultures	Log Number of Bacteria					
		<3	3	4	5	6	>6
Station 6							
D+1	39	15	18	15	33	15	3
D+2	23	13	13	17	22	30	4
D+3	11	46	36	18	0	0	0
D+5*	4	50	25	25	0	0	0
Station 7							
D+1	34	24	6	32	21	6	12
D+2	22	23	14	27	18	14	5
D+3	15	67	20	13	0	0	0
D+5*	9	67	22	11	0	0	0
Station 8							
D+1	21	32	7	32	19	7	3
D+2	4	25	0	25	0	50	0
D+3	8	63	25	8	0	0	0
D+5*	25	92	8	0	0	0	0

* And later.

TABLE 4.9 AEROBIC GRAM-POSITIVE ORGANISMS IN WOUNDS OF SWINE

Expressed to nearest percent of total cultures taken on given days.

Location and Sample Time	Total Cultures	Log Number of Bacteria					
		<3	3	4	5	6	>6
Station 6							
D+1	21	5	0	0	5	29	62
D+2	10	0	0	0	10	10	80
D+3	4	0	0	0	0	100	0
D+5*	3	0	0	33	33	0	33
Station 7							
D+1	16	0	0	0	6	19	75
D+2	16	0	0	0	6	25	69
D+3	8	0	0	0	0	63	38
D+5*	8	0	0	13	50	25	13
Station 8							
D+1	16	0	0	6	6	13	75
D+2	4	0	0	0	0	25	75
D+3	8	0	13	0	0	63	25
D+5*	20	5	15	50	10	10	5

* And later.

TABLE 4.10 ANAEROBIC GRAM-POSITIVE BACTERIA FOUND IN WOUNDS OF SWINE

Expressed to nearest percent of total positive cultures on given days.

Location and Sample Time	Total Cultures	Log Number of Bacteria					
		<3	3	4	5	6	>6
Station 6							
D+1	38	0	0	3	5	42	50
D+2	23	0	0	4	0	44	53
D+3	11	0	0	9	18	64	9
D+5*	3	0	0	67	33	0	0
Station 7							
D+1	33	0	0	0	3	36	61
D+2	22	0	5	0	0	50	45
D+3	15	0	7	0	20	53	20
D+5*	9	0	22	56	22	0	0
Station 8							
D+1	29	0	0	0	14	38	48
D+2	4	25	0	0	0	0	75
D+3	12	0	0	0	17	83	0
D+5*	23	30	8	61	0	0	0

* And later.

TABLE 4.11 RESULTS OF STUDY COMPARING CULTURAL AND FLUORESCENT-ANTIBODY TECHNIQUES

Smears	Fluorescent Smear	Culture
Clostridium perfringens		
18	Positive	Positive
70	Negative	Negative
34	Positive	Negative
13	Negative	Positive
Clostridium novyi		
4	Positive	Positive
94	Negative	Negative
28	Positive	Negative
9	Negative	Positive
Clostridium bifermentans		
1	Positive	Positive
118	Negative	Negative
15	Positive	Negative
1	Negative	Positive

TABLE 4.12 FREQUENCY OF MICROORGANISMS IN BLOOD OF LIVING ANIMALS

Expressed to nearest percent of cultures taken.

Station	Day	Number of Cultures	Percent Positive	Staphylococcus Albus	Staphylococcus Aureus	Beta-hemolytic Streptococcus	Clostridia	Coryne-bacterium	Streptococcus Faecalis	Coliforms	Pasteurella Multocida	Salmonella
6	D+4	42	52	31	2	7	0	2	5	14	2	0
	D+6	29	48	31	0	14	0	3	7	0	7	0
7	D+4	112	38	20	4	2	0	2	1	2	3	0
	D+6	75	48	35	3	4	0	4	7	1	13	3
8	D+4	7	29	29	0	0	0	14	0	0	14	0
	D+6	6	33	17	0	17	0	0	0	0	17	0

TABLE 4.13 FREQUENCY OF MICROORGANISMS IN NECROPSY BLOOD

Expressed to nearest percent of cultures taken.

Survival Time in Days	Number of Cultures	Staphylococcus Albus	Staphylococcus Aureus	Beta-hemolytic Streptococcus	Clostridium	Corynebacterium	Streptococcus Faecalis	Coliforms	Pasteurella Multocida	Salmonella
0 to 3	6	67	33	50	17	0	17	17	0	17
4 to 6	24	42	8	38	8	8	4	4	13	4
7 to 9	29	21	0	10	3	14	10	0	14	0
10 to 12	23	13	4	17	0	0	4	13	13	0
13 to 17	12	8	0	0	0	0	8	0	25	0
Total	94	26	5	20	4	6	6	5	14	2

TABLE 4.14 FREQUENCY OF MICROORGANISMS IN NECROPSY SPLEEN

Expressed to nearest percent of cultures taken.

Survival Time in Days	Number of Cultures	Staphylococcus Albus	Staphylococcus Aureus	Beta-hemolytic Streptococcus	Clostridium	Corynebacterium	Streptococcus Faecalis	Coliforms	Pasteurella Multocida	Salmonella
0 to 3	11	0	9	18	9	9	0	18	0	0
4 to 6	63	38	11	8	3	2	5	11	0	0
7 to 9	64	6	2	5	0	0	14	2	0	2
10 to 12	27	4	0	7	0	0	15	15	0	0
13 to 17	19	0	0	0	0	0	16	5	0	0
Total	184	16	5	7	2	1	10	8	0	1

TABLE 4.15 FREQUENCY OF MICROORGANISMS IN NECROPSY LUNG

Expressed to nearest percent of cultures taken.

Survival Time in Days	Number of Cultures	Staphylococcus Albus	Staphylococcus Aureus	Beta-hemolytic Streptococcus	Clostridium	Corynebacterium	Streptococcus Faecalis	Coliforms	Pasteurella Multocida	Salmonella
0 to 3	4	25	25	50	0	0	25	25	0	0
4 to 6	19	32	0	11	5	11	5	11	5	0
7 to 9	22	18	5	0	0	0	14	14	5	5
10 to 12	4	0	0	0	0	0	25	0	0	0
13 to 17	7	0	0	0	0	0	0	0	0	0
Total	56	20	4	7	2	4	11	11	4	2

TABLE 4.16 FREQUENCY OF MICROORGANISMS IN NECROPSY MEDIASTINAL NODE

Expressed to nearest percent of cultures taken.

Survival Time in Days	Number of Cultures	Staphylococcus Albus	Staphylococcus Aureus	Beta-hemolytic Streptococcus	Clostridium	Corynebacterium	Streptococcus Faecalis	Coliforms	Pasteurella Multocida	Salmonella
0 to 3	7	43	0	43	14	0	14	14	0	0
4 to 6	64	22	2	13	0	3	6	6	2	2
7 to 9	66	9	3	0	0	0	6	5	0	0
10 to 12	28	4	4	0	0	0	0	4	0	0
13 to 17	19	0	0	0	0	0	11	5	0	0
Total	184	13	2	6	1	1	6	5	1	1

TABLE 4.17 FREQUENCY OF MICROORGANISMS IN NECROPSY MESENTERIC NODES

Expressed to nearest percent of cultures taken.

Survival Time in Days	Number of Cultures	Staphylococcus Albus	Staphylococcus Aureus	Beta-hemolytic Streptococcus	Clostridium	Corynebacterium	Streptococcus Faecalis	Coliforms	Pasteurella Multocida	Salmonella
0 to 3	9	22	22	11	0	0	11	11	11	0
4 to 6	61	26	8	3	2	2	8	5	0	2
7 to 9	64	8	0	0	2	2	8	2	0	0
10 to 12	25	0	0	0	0	4	0	4	0	0
13 to 17	18	0	0	0	0	0	11	11	0	0
Total	177	13	14	2	1	2	7	5	1	1

TABLE 4.18 FREQUENCY OF SUBJECTS WITH SPECIFIC MICROORGANISMS FROM MULTIPLE SOURCES

Expressed to nearest percent of cultures taken.

Combined Sources	Number of Cultures	Staphylococcus Albus	Beta-hemolytic Streptococcus	Streptococcus Faecalis	Coliforms	Pasteurella Multocida
Feces, necropsy	176	29	2	20	14	1
Feces, blood	163	15	1	3	2	0
Feces, blood, necropsy	131	8	1	5	2	0
Feces, wound	101	62	14	72	62	0
Wound, necropsy	63	30	16	25	14	0
Wound, blood	60	7	8	0	2	0
Blood, necropsy	134	10	2	3	2	2

Chapter 5

HEMATOLOGY

5.1 BACKGROUND

Several years ago it was demonstrated that, under certain conditions, administration of bone marrow or spleen cell suspensions can prevent death in otherwise fatally irradiated animals (Reference 22). This observation has resulted in many studies designed to delineate the limits of the phenomenon. Several species of small animals have been treated successfully. Isologous, homologous, and heterologous tissues have been administered intact or in a homogenized state by any of several routes. Most of the studies to date have used X or gamma irradiation, but the response after other types of exposure is now being explored.

Investigations by others have suggested that the results of such therapy may depend upon the irradiated animals' size, species, and strain, as well as upon the rate of irradiation and weight, and the charge and speed of irradiating particles.

This phenomenon poses the possibility of using such therapy in the treatment of human casualties exposed to radiation from nuclear detonations. Studies designed to explore this possibility require experiments on larger animals (comparable to man in size) under controlled laboratory conditions.

It has not been demonstrated that the relatively huge hematopoietic organ of a large mammal (perhaps 1,000 grams for a 120-pound pig or man) can regenerate as readily after exposure and therapy as can the smaller organ (approximately 150 mg) of a mouse.

In addition, available evidence (Reference 23) suggests that the cause of death following fission-neutron irradiation may not be due primarily to hematopoietic failure. If this is so, replacement of the bone marrow might not have the same beneficial effects on survival as has been demonstrated on smaller animals after irradiation with X rays, gamma rays, or fast neutrons (References 23 and 24).

A corollary in this problem is the rapid screening of patients to determine qualitative and quantitative exposure to ionizing radiation. Film badge dosimetry is time consuming, and under field conditions, subject to gross inaccuracy (Chapter 8). A rapid, more reliable screening procedure is the determination of the total leukocyte count. Mass blood counts may also be time consuming and require much equipment such as counting chambers and pipettes. This latter problem was given to the Department of Hematology, WRAIR, for exploration of possible solutions.

Attempts to estimate the white cell counts from blood smears proved unsuccessful. The degree of anemia and thickness of the smear were cumbersome variables when the red cells were used as a point of reference. However, a method of scanning was found to be feasible if a standard volume of blood could be delivered to the microscopic slide. There was thus developed the "pinhead leukocyte count" (Reference 25).

5.2 PREPARATION OF BONE-MARROW SUSPENSION

The cell suspensions were obtained from donor pigs of the same stock, weighing 35 to 70 pounds. Each donor was bled several hundred milliliters, then killed by means of an intracardiac injection of air. Donor serum was mixed with normal saline solution, one part to ten, as the medium for suspension of the cells.

The long bones were removed from the animal and split lengthwise; the marrow was scooped out and suspended in solution. It was found that the long bones of very young pigs are filled with cancellous tissue, and those from older pigs contained much fat. The difficulties of removing bone spicules from suspensions of the former, and fat globules from suspensions of the latter, was found to impair their usefulness.

The spine was removed intact through a dorsal incision (Figure 5.1). A $\frac{1}{4}$-inch square steel rod was driven through the spinal canal and anchored at both ends to a wooden block. A 6-inch jack plane was used to plane down the vertebral bodies (Figure 5.2), and the planings were dropped into the serum-saline solution. After being shaken, the planings were allowed to settle, and the saline solution was changed. This was repeated twice. By this time most of the marrow cells had been shaken loose from the bony fragments.

The spleen was cut into chunks, which were placed in a mortar with a stainless steel screen at the bottom (Figures 5.3 and 5.4). The handle of a syringe was used as a pestle to force the spleen pulp through the screen. The pulp was shaken in solution and strained through the screen again.

The cell concentration in each of the three solutions was determined by counting in a hemocytometer chamber, and all three solutions were mixed together prior to injection. Contributions from each of the three sources were nearly equal in the final solutions. The time from death of the donor pigs to administration of cell suspension was 90 to 120 minutes. Each donor pig supplied homogenate for eight to ten recipient pigs. The final solution was administered by intravenous (marginal ear veins), intracardiac, or intraperitoneal route. The volume of solution was 10 to 25 ml.

5.3 METHOD OF THERAPY

Each treated animal received 3 to 4×10^9 nucleated cells between 4 and 8 hours after exposure. Sixty-eight animals were treated and divided into six groups (Table 5.1). The clinical course of each animal was carefully followed; however, no peripheral blood counts were done, because background studies demonstrated that trauma of handling swine that had received supralethal doses of radiation contributed significantly to their morbidity. All swine were autopsied.

One animal died promptly of cerebral embolism as a consequence of intracardiac injection. Approximately 15 percent of the animals treated by intravenous or intracardiac injection exhibited mild symptoms of cerebral embolization, such as ataxia and staggering. At autopsy, animals that received intravascular injections demonstrated multiple small emboli in many organs. Similar lesions were not seen in animals receiving intraperitoneal injections.

5.4 TECHNIQUE OF PINHEAD COUNT AND METHODS

The detailed method of the pinhead count is given in Reference 25. Briefly, the amount of blood which can be transferred on the head of a straight pin is placed on a slide, air-dried, and stained with methylene blue or Giemsa stain after preliminary

immersion in a solution of 3 percent formalin and 0.1 percent stain in tapwater. The hemoglobin was leached out by the water, the smear was fixed by the formalin, and the leukocytes were stained. Chamber counts were performed as described in standard laboratory manuals.

Two animals were evaluated from each station on the 120-degree and 204-degree lines of Shot Wilson. These twenty animals had pre-irradiation white blood counts. A total of 44 animals are included in the study. These animals, with one exception, had died by the thirteenth day after irradiation. Peripheral white blood counts were obtained on the fifth, tenth, fifteenth, and twentieth days after irradiation, by means of the standard chamber counting methods. In addition, daily peripheral white blood counts were obtained on these 44 swine by the pinhead technique both before and after exposure to radiation.

The peripheral white blood counts obtained by the standard chamber method were plotted against dose for each of the days obtained after irradiation (Figures 5.5 through 5.8). White blood counts (WBC) in thousands are on the ordinate, and doses in reps are on the abscissa. To obtain the correlation between pinhead counts and chamber counts, these results were plotted against each other (Figure 5.9).

Following Shot Priscilla, approximately 100 casualties were evaluated by the pinhead leukocyte count. Daily white blood counts were obtained to follow the clinical course of the wounded swine, and sufficient controls were run to continue the plot (Figure 5.10).

5.5 RESULTS

After Shot Franklin, the animals in Groups A and B were permanent survivors. None of them became ill as a consequence of either the irradiation or the transfusion of splenic and marrow cells.

During Shot Wilson, the animals in Groups C and D received supralethal levels of irradiation. Two died immediately; one had received the transfusion intravenously through an ear vein and the other by intracardiac injection. Post-mortem examination of the latter showed the injection had been into the right ventricle. Both animals demonstrated at autopsy evidence of radiation injury. The remaining sixteen animals died within 8 days. Their average survival time was no better than that of other animals exposed at the same time to comparable levels of radiation.

Among the thirteen animals in Group E exposed during Shot Priscilla at Station 7, the first death occurred on D+5, and all the animals were dead by D+15. Among seventeen pigs in Group F exposed at Station 8, the first death was recorded on D+8. There were eleven survivors on D+21, all vigorous and active, which were returned to WRAIR for long-term followup. None of the animals at Station 9 expired. The average survival of the treated animals from each of the three stations during Shot Priscilla was not significantly different from that of untreated animals from the same stations.

All of the animals, post mortem, demonstrated the pathologic changes characteristic of radiation illness. There was no evidence of regeneration of the bone marrow attributable to the therapy.

5.6 DISCUSSION AND CONCLUSIONS

Field experiments confirmed the correlation between leukopenia and total-body irradiation. Technicians performing the pinhead count quickly accepted this technique because of the saving in time and the relative accuracy of the procedure. With white blood counts above 15,000, there was a tendency for the technician to underestimate the true

count; this is attributed to the crowded picture of multiple dots in the microscopic field. In the range below 10,000, the correlation is better. In the range of radiation-lowered white blood counts in humans, below 5,000, the technique appears to be entirely acceptable (Figure 5.10).

Relative to the transfusions of homologous spleen and marrow cells, under the conditions of the experiment, the transfusion of such cells following exposure to lethal levels of total-body irradiation was not effective in preventing death of the swine. The animals exposed to insignificant levels (Shot Franklin) of total-body irradiation were not harmed, suggesting that the transfusion itself was not especially deleterious. However, the multiple small infarctions found post mortem in the animals exposed to Shot Wilson indicated that the cellular suspension injected into the circulatory system produced widespread embolization. It was for this reason that the animals exposed to Shot Priscilla received the transfusion intraperitoneally.

Although splenic tissues administered intraperitoneally are an effective method of preventing the death of irradiated mice, this route of administration has not been proved in the pig. Other facets of this procedure in the pig must be investigated further, such as: (1) its response to trauma and therapy (the pig is a large animal, whereas mice and rats are smaller; therefore, the pig responds to trauma and subsequent therapy in a different fashion); (2) age factors (the pigs used were of early adult age when compared to humans); (3) the quality and optimum dose of the transfused material, as well as the route of the transfusion; and (4) the quality of the irradiation, i.e., mixed gamma rays and neutrons.

TABLE 5.1 THERAPY OF SWINE, AND SURVIVAL RATE

Group	Gamma	Neutron	Cells	Therapy Route*	30-day Survivals			
					Treated	Animals	Control	Animals
	rep	rep			pct	No.	pct	
A	10	10	3×10^9	IV	100	10	100	10
B	10	10	3×10^9	IV	100	10	100	10
C	725	715	3×10^9	IV or IC	0	9	—	—
D	660	640	3×10^9	IV or IC	0	9	0	10
E	435	180	4×10^9	IP	0	13	4	142
F	197	71	4×10^9	IP	65	17	65	107

* IV, intravenous; IC, intracardiac; IP, intraperitoneal.

Figure 5.1 Removing swine vertebra. Scalpel touches spleen.

Figure 5.2 Jack plane extracting vertebral marrow.

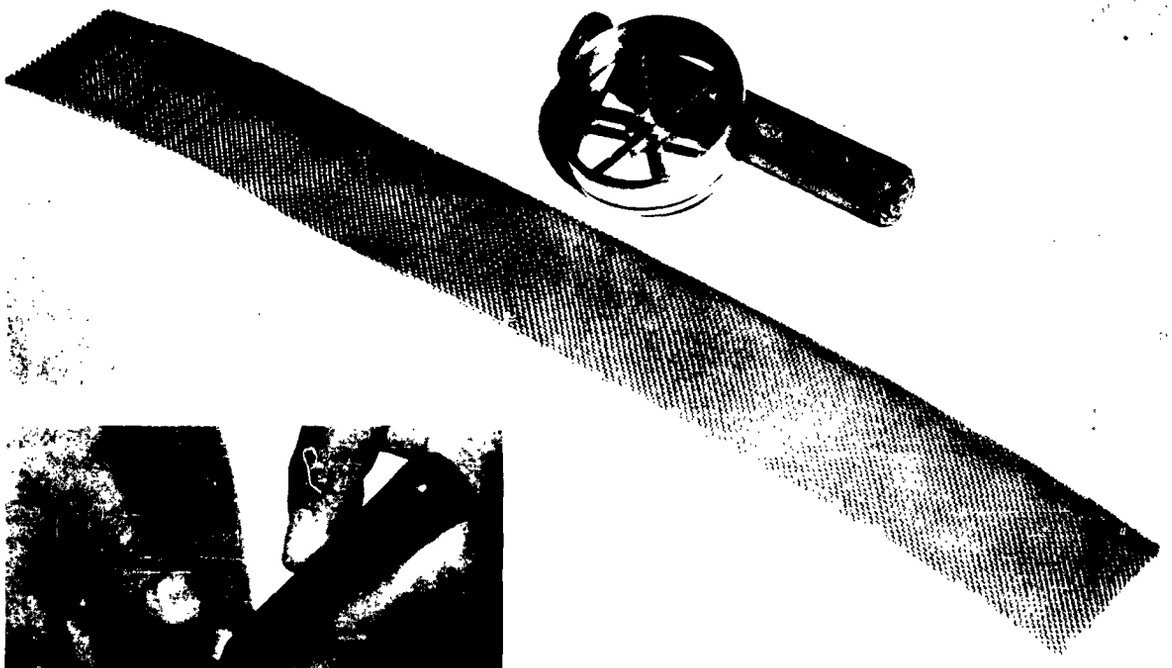


Figure 5.3 Materials for mortar.

Figure 5.4 Assembled mortar.

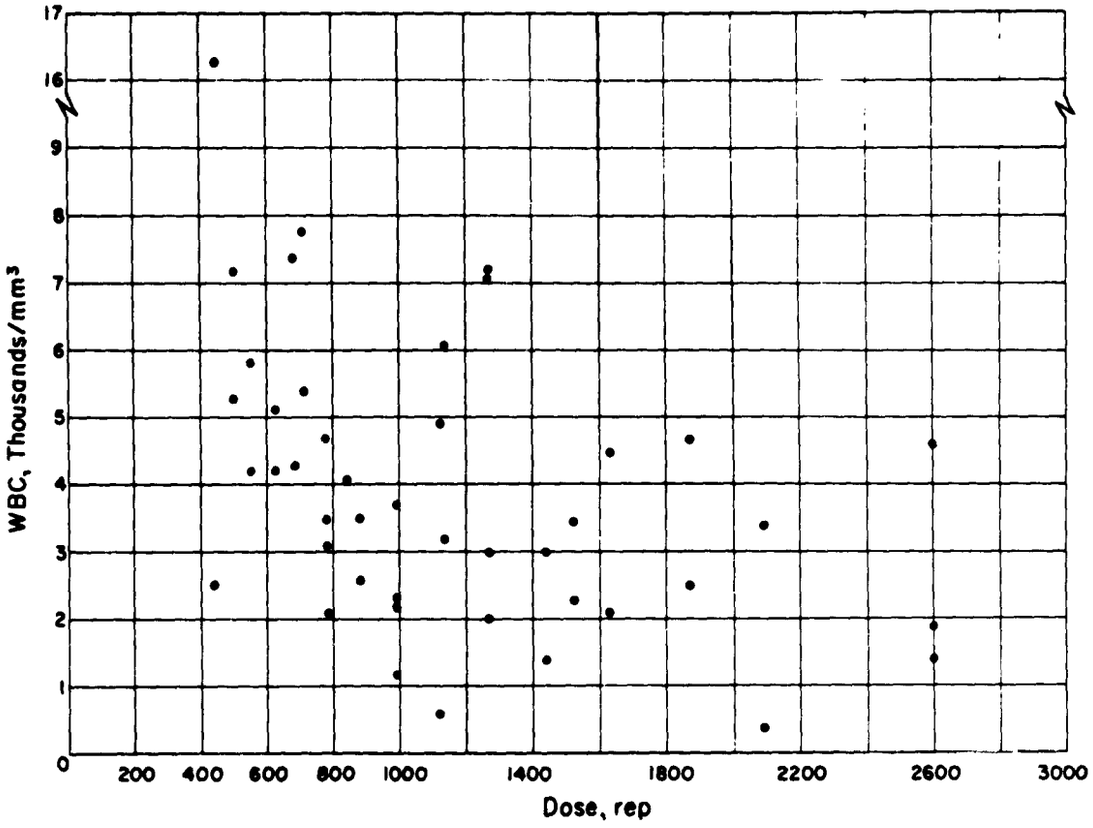


Figure 5.5 White blood count versus dose, third day after exposure.

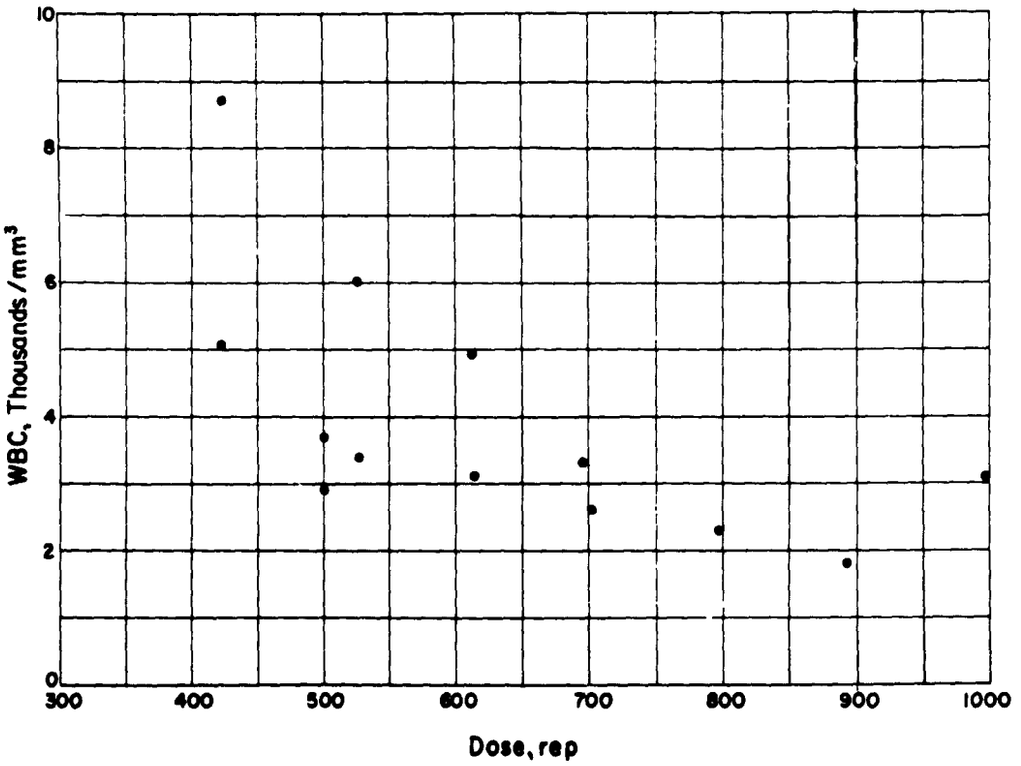


Figure 5.6 White blood count versus dose, tenth day after exposure.

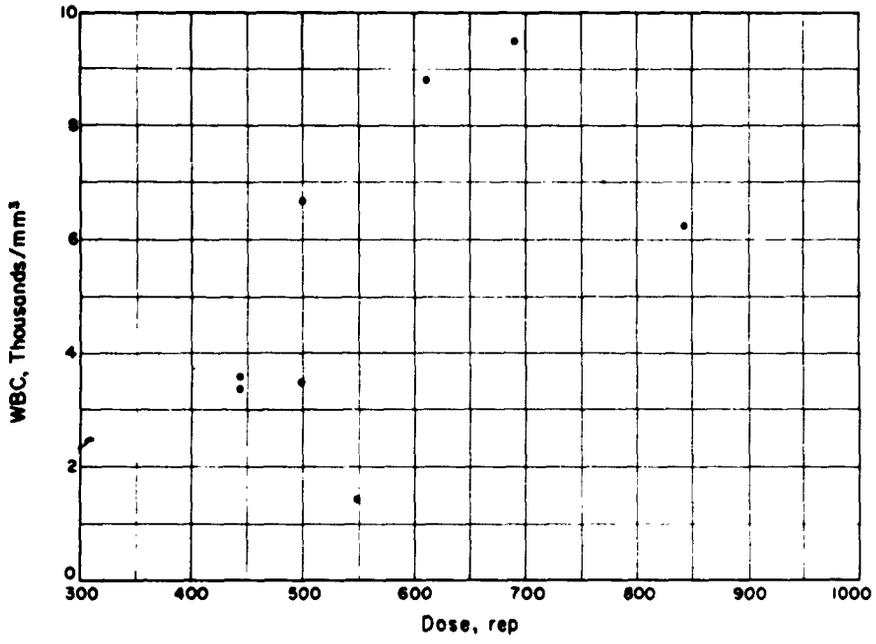


Figure 5.7 White blood count versus dose, sixteenth day after exposure.

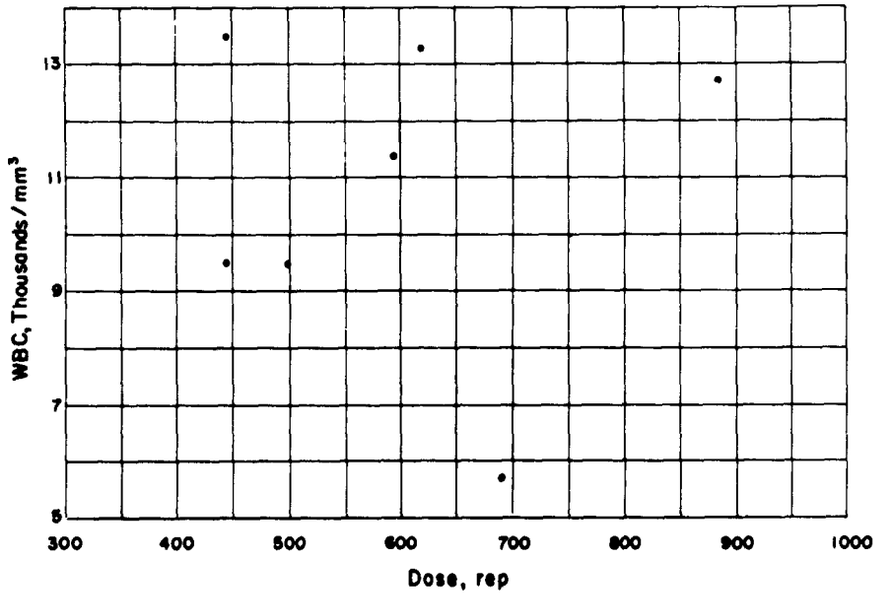


Figure 5.8 White blood count versus dose, twenty-second day after exposure.

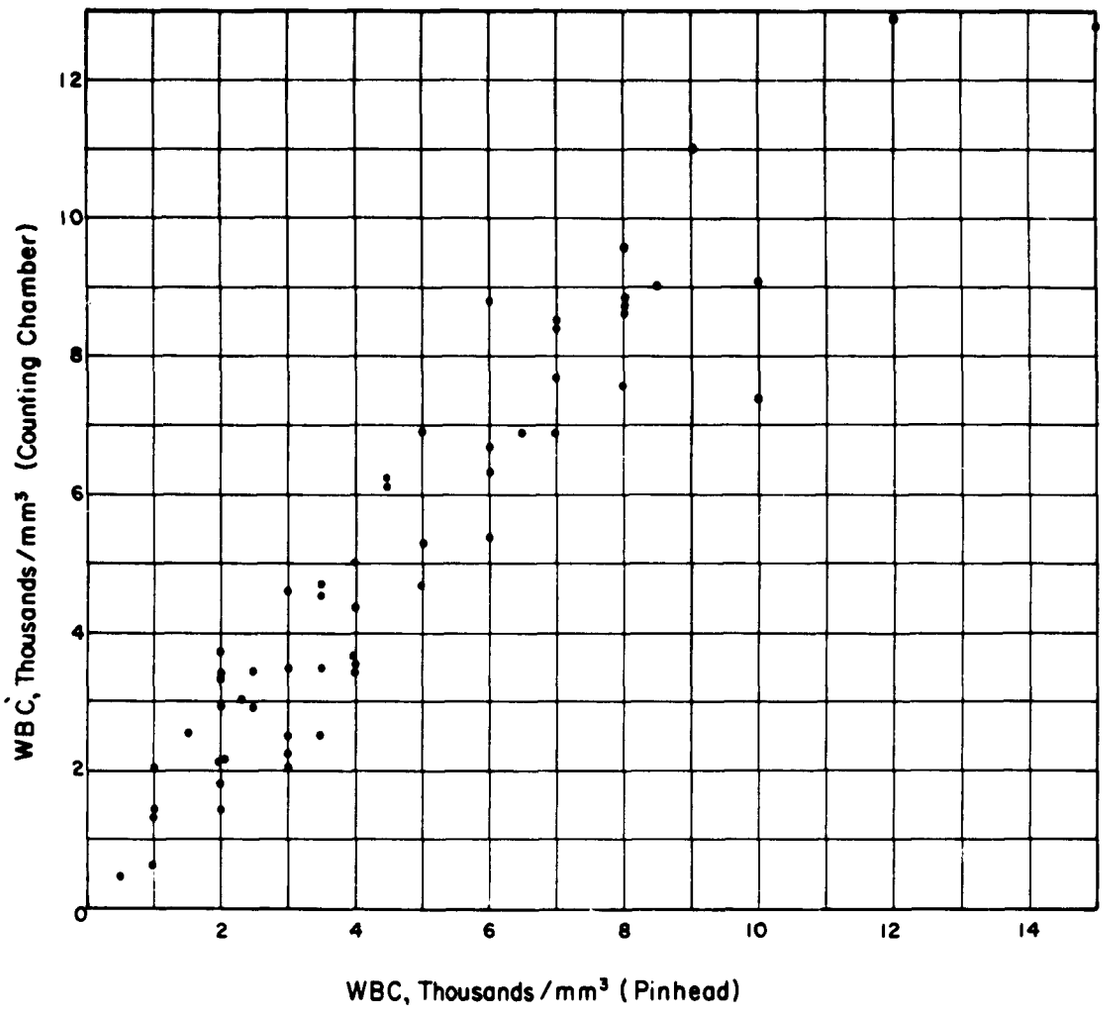


Figure 5.9 White blood count, pinhead versus chamber counts.

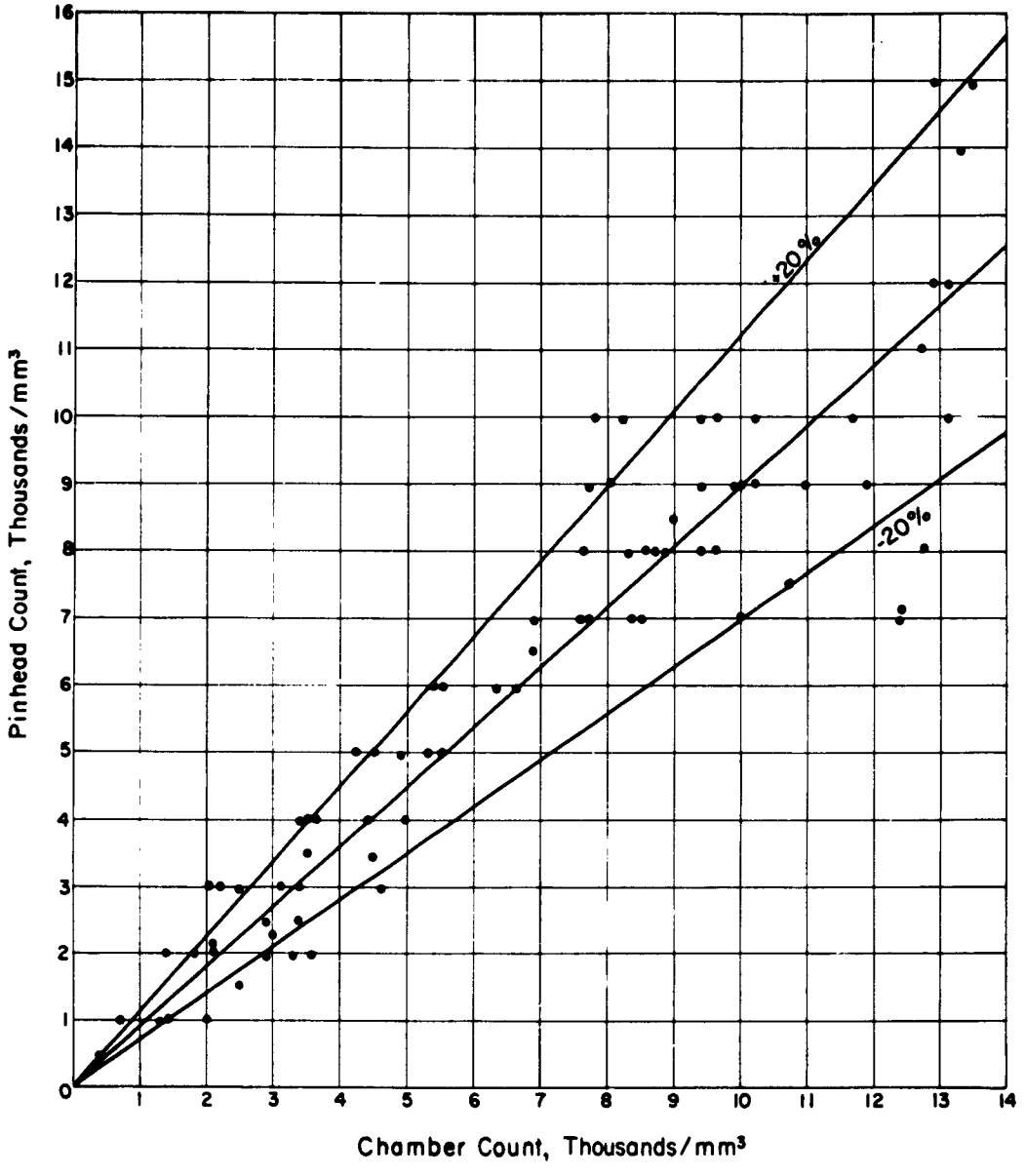


Figure 5.10 White blood count, pinhead versus chamber counts.

Chapter 6

PATHOLOGY

6.1 INTRODUCTION

Considerable data exists, both from laboratory and field studies, on the reaction of various tissues to whole-body irradiation. However, the nature of the nuclear devices tested in the field during Operation Plumbbob resulted in the exposure of swine to amounts and types of whole-body irradiation that have not had accurate documentation as far as the tissue response goes. In addition to the general tissue response, the analysis of some of the histopathological features present in animals surviving the initial shot were of interest. Among these were the cytologic relationships of the spleen as a fundamentally lymphopoietic organ, and as an index of radiation effect.

The significant portion of this overall pathologic study arose from the support of the numerous projects centered about the experimental animal group. One feature was the provision of an early gross pathologic diagnosis. This proved particularly useful in the preexposure phase of the program as an indication of intercurrent infection, the stability of the experimental animal group, and as a factor in management. It is a further indication of a baseline of distinct value in the overall analysis of data.

Other aspects of the relatively complete pathologic procedure were in direct support of the clinical data, specifically the radiation lethality studies in one series, and the combined radiation, burn, and trauma effects in the series for Shot Priscilla.

While the detailed and systematic microscopic reporting of all tissues has not been contemplated, certain general reviews and certain specific projects have been undertaken. This chapter covers the facets of the general response which are considered to be unique or significantly different, and a detailed discussion of the splenic cytologic findings in tissue sections and imprints made at autopsy.

6.2 PROCEDURE

All dead animals were necropsied as soon as possible after death. The delay between death of an animal and autopsy in the majority of cases was less than 2 hours. In the one instance of a high peak load (Shot Priscilla) the animals were placed in plastic bags and immersed in a mixture of ice and water for a period of 10 to 12 hours with satisfactory preservation. The pathology group functioned through the 24-hour period. Animals representing duplicate position and time of death were discarded for a relatively short time during the interval in which the peak mortality from Shots Priscilla and Wilson coincided. The fact that the mortality peaks of both detonations did coincide resulted in an exceptional load on the pathology facilities and personnel.

A standard necropsy procedure, including a thorough examination of the external surfaces, thorax, abdomen and the organs therein, as well as a pretested standard form of a written animal necropsy record were of definite help in handling the peak load of

pathologic work. Gross photography supported the prosector's verbal recorded description whenever possible.

After Shot Wilson 261 (out of 304) animals were autopsied, gross-necropsy observations recorded, and tissue samples taken. During Shot Priscilla, 719 animals were exposed. These animals were necropsied in order to determine cause of death, e.g., missile trauma versus radiation effects; to record burn and missile data; and to take selected tissue samples. The standard necropsy records were maintained and radiation effect was evaluated on gross-anatomic examination at the time of autopsy.

For the subproject of spleen cytology in exposed animals, fresh crosscuts of spleens were made, and three imprints of each spleen were prepared in the following way: the imprints were immediately fixed in 95 percent ethyl alcohol, and one later stained with a hematologic stain (combined Wright-Giemsa stain), another with Papanicolaou stain, and the third with Feulgen stain for desoxyribonucleic acid. Corresponding spleen tissue portion (inclusive of the cut surface from which imprints were prepared) was fixed in neutral buffered formalin, processed later in the laboratory in the usual way, and stained with hematoxylin-eosin. Despite the difficulties and pitfalls in field preparation of delicate hematologic staining and cytochemical stains, over 5,000 imprints and tissue sections (including those obtained before Shots Wilson and Priscilla) were prepared and evaluated at the Armed Forces Institute of Pathology.

6.3 RESULTS

6.3.1 Autopsy Findings. The control group consisted of nonexposed animals. These were sacrificed or died spontaneously. Data was obtained on seventy animals in control groups. The major pathologic findings are summarized in Table 6.1.

As Table 6.1 indicates, hemorrhagic gastroenteritis was found to be one of the most prevalent causes of death in the control group. It should be noted also that the manifestations of postvaccinal hog cholera very frequently included hemorrhagic events in the gastrointestinal tract. Thus, almost half of this group died showing hemorrphagic phenomena. The incidence of bronchopneumonia should be noted here also, inasmuch as pulmonary pathology and/or hemorrhagic diathesis constituted the major pathologic changes observed in groups exposed to Shots Wilson and Priscilla.

The gross pathology of the animals exposed during Shot Wilson is tabulated under the headings of three subgroups. Subgroup 1 includes animals receiving an ionizing radiation dose causing LD_{100} in 2 to 6 days. Subgroup 2 includes animals receiving ionizing radiation dose causing LD_{100} in 6 to 14 days. Subgroup 3 includes animals receiving ionizing radiation dose causing LD_{100} in 16 to 30 days.

Reference to group average body weights indicates an early loss in body weight related to the higher levels of radiation dose, an observation confirmed by more detailed studies (Chapter 2). There is indication in organ weights of greater lung pathology with longer survival periods, and greater spleen destruction (or average weight loss) in the higher dose ranges (Table 6.2). This coincides with the general pathologic observations.

The distribution of gross pathologic findings by organ or area and subgroups is indicated in Table 6.3. Hemorrhage in lymph nodes and tonsils is seen to be the most frequent general index of radiation effect. Hemorrhagic manifestations, pulmonary pathology, and ulcerative lesions of the gastrointestinal tract are the prominent features of the pathologic picture as noted in the summary of major findings (Table 6.4).

6.3.2 Spleen Cytology. Cellular classification and counts of spleen imprints were made on all slides permitting satisfactory determination. A standardized splenogram sheet is shown in Figure 6.36.

For the control animals, the wide range of primary pathologic processes established at the necropsy table gives some hint of the fact that rather widespread numerical values in spleen differential counts might be expected. It became obvious that at least five distinct patterns in spleen cytology (and histology) are to be established, namely: (1) predominantly lymphoid, (2) lymphoid-reticular, (3) reticular, (4) hemopoietic, and (5) chronic inflammatory. These patterns are reflected by different types of cell populations within the spleen. The individual cells in these imprints showed no distinct morphologic changes, the entire pattern being determined by relative number of each cell type rather than by an appearance of distinctive or pathologic cells. The notable exception was found in the reticular type of spleen; here atypical cells were frequently found. Hog cholera was indicated on the autopsy sheets in these cases. It is evident that evaluation of spleen cytology changes in exposed animals should take into account this significant variation in cell composition when considering possible effects on the spleen cytology of exposure to ionizing radiation.

Both the differential cellular count and morphologic analysis sheets were used for evaluation of spleen cytology in exposed animal groups. This included matching of individual imprints with corresponding tissue sections and an evaluation of morphologic changes including: degree of destruction of lymphocytes, mitotic activity, presence of nonphagocytized cell debris, number of phagocytes (erythrophagocytes included), appearance of fibrinoid networks, increase or decrease of polymorphonuclear leukocytes, eosinophils, degenerated reticuloendothelial (RE) cells, presence of atypical RE cells, syncytial RE cells, marginal spindling in evaluation of regeneration, presence of baccolonies, degree and site of hemorrhages, content of red pulp, and vascular and connective tissue injury.

For Shot Wilson, to facilitate the evaluation of cytologic changes in the spleen, the pertinent findings are classified under the three subgroup headings, corresponding to those used in tabulation of gross pathologic data (Section 6.3.1).

In Subgroup 1, there was maximal destruction of mature lymphocytes. Although the phagocytosis of cellular debris was evident in all cases, cellular nonphagocyted fragments persisted till the sixth day. Therefore, in this dose range, certain imbalance between cell destruction and phagocytosis was evident. The population of polymorphonuclear leukocytes did not show appreciable changes in quantity, including eosinophils.

The reticuloendothelial elements underwent pronounced changes in all animals of this subgroup. Degenerated RE cells, later atypical probably viable RE cells, spindling of RE cells, as well as syncytial RE formation were common findings. The epithelioid centers in lymphoid follicles were conspicuous and prominent. Above the 9,000-r level, the epithelioid changes at the central portion of the follicle were the most outstanding feature. There was no increase in plasmacytoid cells. Follicular hemorrhages were absent despite the hemorrhagic syndrome observed at autopsy. The injury to RE system was paralleled by degenerative changes in splenic stroma. Smooth muscle fibers appeared distorted with pyknotic nuclei. There were fibrinoid-hyaline changes in arterial walls, as well as vacuolization of stromal fibrocytes.

In Subgroup 2, the relative number of small lymphocytes was found reduced to 25 percent and 50 percent of normal values. The mitotic activity in lymphoid follicles reappeared rather sluggishly and in only a few instances were values above normal found. Nonphagocyted cell debris was still present in some animals in higher dosage levels

(1,300 r and more). Phagocytes were more numerous than in Subgroup 1. Focal fibrinoid changes were found in all animals. Polymorphonuclear leukocytes were increased above normal (30 percent of imprints). The RE cells showed obvious degenerative changes in the higher dosage levels (above 1,300 r) in this subgroup. Atypical RE cells were numerous. This category includes the nonclassifiable large cells, undifferentiated stem cells, binucleated basophilic cells, and giant mononuclear cells. Spindling of RE cells as well as syncytial RE elements were of rare occurrence. Epithelioid centers were not present in spleens of this subgroup. On the other hand, in contrast with Subgroup 1, plasmacytoid cells appeared to be more and more numerous as related to survival time and dose levels. A parallel process was reflected in the repopulation of spleens with lymphocytes. Evidence of a moderate to severe follicular hemorrhage was present in more than 75 percent of spleen imprints and sections. Similar incidence of bacterial colonies—predominantly plump short rods— was noted. Review of tissue sections revealed, in 45 percent of these cases, splenic bacterial colonies of antemortem origin. The injury to the blood vessels was evident in the tissue sections.

In Subgroup 3, the relative lymphocyte count revealed a wide range from slightly below normal to 75 percent decrease. Although mitotic activity was observed frequently, cell debris reappeared in lymphoid follicles, without concomitant increase in polymorphonuclear leukocytes, but invariably accompanied by bacterial colonies and hemorrhages. This combination of phenomena is considered to represent a destruction of regenerated lymphoid tissue due to septicemia. The atypical RE cells were still present in spleen imprints as well as a considerable number of plasmacytoid cells. Thus, despite the superimposed septicemia, morphologic evidence of underlying radiation injury could be detected.

6.4 DISCUSSION

The main feature of the ionizing radiation syndrome in supralethal and lethal levels was the hemorrhagic syndrome as manifested by widespread hemorrhages within the animal tissues. This syndrome occurred as early as 2 days after exposure. In contrast to the acute radiation syndrome in man (in supralethal or lethal doses), the fatal disruption of hemostatic mechanisms in swine appears very early. The survey of human Nagasaki and Hiroshima material (Reference 26) revealed the appearance of the hemorrhagic syndrome generally no earlier than 20 days after exposure, regardless of the dose received by a particular individual. Similarly, an accidental exposure of an individual to combined gamma and neutron radiation (estimated total dose of 1,900 rep) resulted in death within 9 days, with no hemorrhagic syndrome apparent (Reference 27).

On the other hand, previous experience with swine exposed to ionizing radiation ($LD_{100/7}$) from an atomic bomb (Reference 28) indicates considerable difference in severity of hemorrhagic phenomena in exposed sacrificed animals as compared with spontaneously dying exposed animals at the same dose level. The latter animals showed capillary dilatation engorgement and hemorrhages, and bacterial colonies widely scattered throughout the body. The sacrificed exposed swine did not show hemorrhagic manifestations of similar magnitude, or septicemia. It should be added here that control animals were found to die with manifestations of hemorrhagic diathesis, although certain differences in degree were well established. If not for other reasons, this pronounced bleeding tendency in swine renders the radiation injury data difficult to extrapolate to man.

The cytology of the spleen proved to be a rather delicate tool for the evaluation of radiation injury under field conditions. The technical preparation of imprints is

difficult even under well-standardized laboratory conditions. For this reason, it is apparent that any adverse field condition will greatly decrease the technical performance and thus the usability of spleen imprints. In addition, the interpretation of technically excellent spleen imprints is a complicated task by itself, demanding considerable experience in this particular area. Despite technical difficulties inherent in this method, the cytology of spleen imprints proved to be of definite value for advanced studies of radiation injury to this lympho-hemapoietic organ, but of little value (at the present time) for assessing the degree of radiation injury for each animal. Additional laboratory work under controlled conditions is needed to develop the full possibilities of spleen cytology into an index of severity of radiation injury in each individual (Figures 6.1 through 6.35). Figures 6.9 through 6.18, representing typical cell forms encountered in the bone marrow of the preshot control group, are provided to assist in the evaluation of the spleen imprints.

6.5 CONCLUSIONS

Hemorrhagic findings were present in approximately half of the preshot control group at necropsy.

Bronchopneumonia was the major cause of death in 9 of 70 cases (13 percent in the preshot control group).

Hemorrhage within lymphoid and tonsillar tissue is the most frequent general pathologic index of radiation effect.

As indicated by the pathology of the control group (nonexposed swine) under somewhat adverse field conditions, it is necessary to delineate the extent of the hemostatic mechanisms which may enter the picture in both control and exposed animals.

Certain technical considerations in spleen cytologic preparations in the field tend to limit the application of this technique to special studies.

Splenic imprint cytology interpretation (splenogram) serves to broaden the interpretation of splenic and body responses but, at the present stage, does not provide a specific index of the individual animal to radiation.

TABLE 6.1 PATHOLOGY OF CONTROL ANIMALS

Major Diagnosis	Number of Animals
Accidental deaths, anesthetic deaths, surgical deaths	10
Sepsis	9
Bronchopneumonia	9
Hemorrhagic gastroenteritis including GI hemorrhage	17
Cholera, postvaccinal	17
Intestinal obstruction	2
Anemia	1
Hydronephrosis	1
Unknown (including autolyzed carcasses)	4
	70

TABLE 6.2 AVERAGE ORGAN WEIGHTS IN GRAMS/PERCENT OF BODY WEIGHT

	Subgroup		
	1	2	3
Dose range (r plus rep)	13,290 - 2,185	1,935 - 730	760 - 410
LD_{100}	2 to 6 days	7 to 14 days	16 to 30 days
Number of animals	60	128	42
Body weight (at time of autopsy)	63.3 lb	77.9 lb	84.9 lb
	28,674 gm	35,288 gm	38,459 gm
Heart	144/0.5 pct	155/0.44 pct	166/0.43 pct
Lung: right	241/0.84 pct	405/1.15 pct	560/1.46 pct
left	196/0.68 pct	285/0.81 pct	338/0.88 pct
Spleen	52/0.18 pct	61/0.17 pct	70/0.18 pct
Liver	1,060/3.70 pct	1,187/3.36 pct	1,266/3.29 pct
Kidney (combined)	83/0.29 pct	93/0.26 pct	126/0.33 pct
Adrenal (combined)	6.5/0.02 pct	7.5/0.02 pct	7.7/0.02 pct

TABLE 6.3 GROSS PATHOLOGIC FINDINGS, SHOT WILSON

	Subgroup		
	1	2	3
Number of animals	60	128	42
Skin: petechiae	1	21	6
extensive burns	37*	None	None
lacerations	17*	3	None
Ascites	2	9	5
Peritonitis	None	1	None
Heart: petechiae and hemorrhage	21	84	39
Lung: edema	8	22	7
hemorrhage	8	36	14
hemorrhagic pneumonia	1	19	9
bronchopneumonia	18	56	18
Spleen: hemorrhage and petechiae	15	14	5
Lymph nodes and tonsils: hemorrhage	34	97	37
Gastrointestinal tract: hemorrhage	31	89	36
hemorrhage and ulcer	6	10	3
ulcer (including enteritis, and colitis)	5	23	3
Kidney: hemorrhage (parenchymal)	1	16	20
hemorrhage and petechiae in pelvis	None	14	11
Adrenal: hemorrhage	5	4	2
Septicemia	2	3	1

* The data from 40 animals (Appendix A) placed for preliminary combined trauma, burn, and irradiation data are included in this portion of the analysis because of similarity of the pathology pattern to the remainder of the group.

TABLE 6.4 MAJOR PATHOLOGIC FINDINGS

	Subgroup		
	1	2	3
Hemorrhagic syndrome	37	109	39
Bronchopneumonia	18	56	18
Gastrointestinal ulcers (also ileitis, cecitis, and colitis)	5	23	3
Thermal burns and irradiation	36*	None	None

* The data from 40 animals (Appendix A) placed for preliminary combined trauma, burn, and irradiation data are included in this portion of the analysis because of similarity of the pathology pattern to the remainder of the group.

SPLENIC IMPRINT CYTOLOGY IN UNEXPOSED SWINE

Fig. 6.1 The reticulo-endothelial cells lining splenic sinusoids are shown here. Note large nuclei, fine chromatin, nuclear membrane and syncytium-like formation suggesting tubular formation.

Fig. 6.2 This group of rather large cells with pale, non-granulated, and abundant cytoplasm is identifiable as undifferentiated reticulum cells and stem cells. The differentiation between these two cell types (corresponding to stages of maturation) is guided by nuclear chromatin pattern. The primitive RE cell possesses somewhat paler nucleus with fine chromatin pattern (cell in left lower corner). These cell types are variously named as germinal center cells, undifferentiated RE cells, stem or blast cells. The cell in the right lower portion of this figure represents a differentiated reticulum cell comparable to those of Fig. 6.1.

Fig. 6.3 Reticulo-endothelial cells may assume spindle-shaped forms in splenic stroma and in peri-arterial sheets.

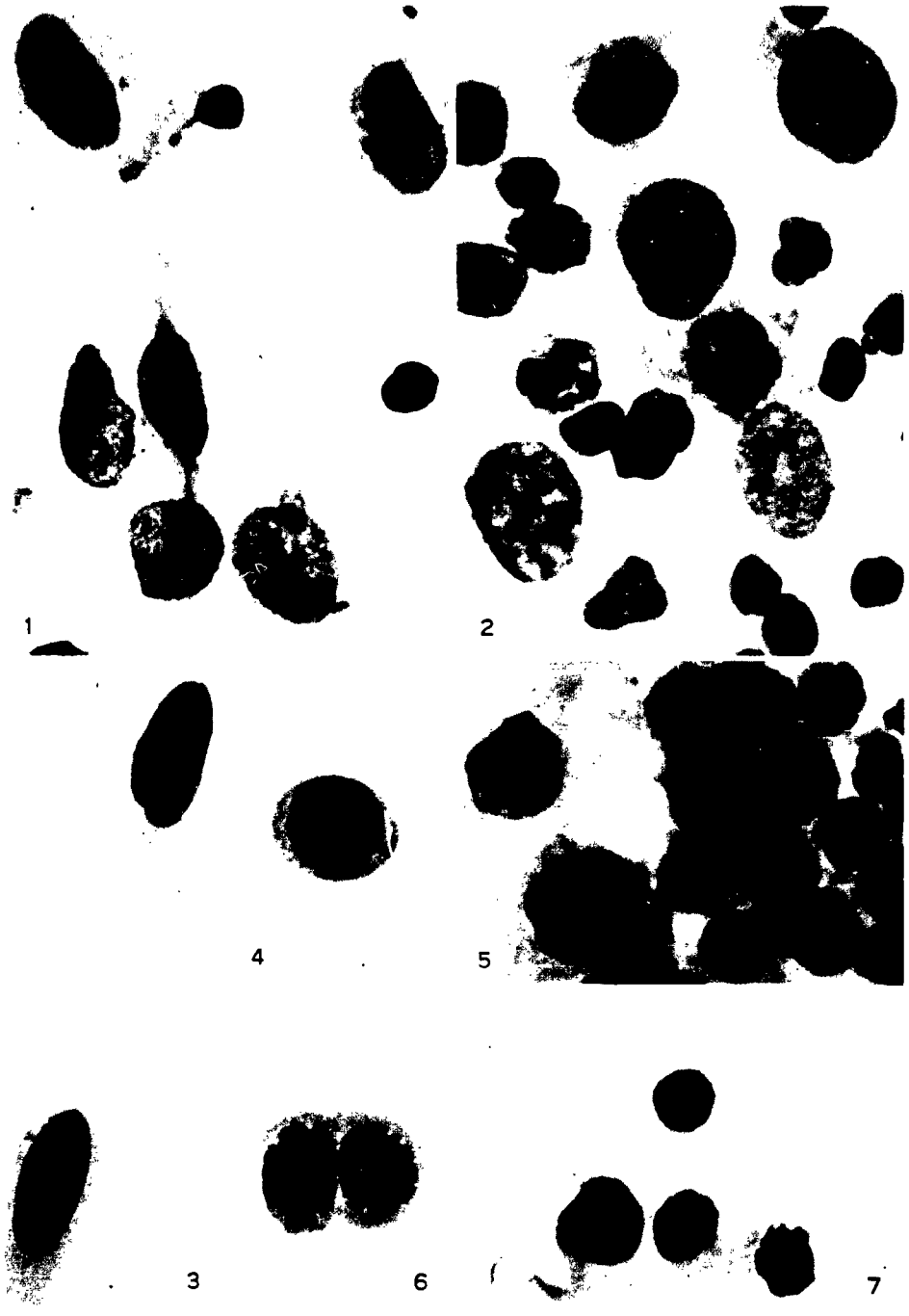
Fig. 6.4 The established morphologic criteria for mature lymphocytes are also valid in spleen imprints.

Fig. 6.5 This represents the predominant pattern encountered in swine splenic imprints and is comparable in general morphologic criteria to that seen in human cytology. Typical also of spleen imprints of swine is the occurrence of a few neutrophils and a number of eosinophilic granulocytes. Erythropoietic foci are seen only infrequently.

Fig. 6.6 Typical normoblasts are occasionally encountered in spleen of swine.

Fig. 6.7 Typical small plasma cells seen in imprints from non-exposed animals. The differential count on these imprints gave values up to 4% of plasma cells.

Imprints fixed in 95% alcohol after rapid drying. Wright-Giemsa stain. Magnification 1300X.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BONE MARROW CYTOLOGY IN UNEXPOSED SWINE

Fig. 6.8 Typical grouping of normoblasts at various stages of maturation, promyelocyte, metamyelocyte, and stem cells.

Fig. 6.9 Cells ranging from myeloblast to metamyelocyte represent a focus of myeloid activity of the type seen frequently in the marrow.

Fig. 6.10 A grouping of relatively mature myeloid cells with stem cell at lower margin. Late eosinophilic metamyelocyte, upper center, is a common form and is noted frequently in the peripheral blood. This indicates also the typical appearance of the neutrophilic leukocyte by standard staining procedures - characterized often by few granules and minimal staining of those present.

Fig. 6.11 Stem cell or myeloblast centrally, more differentiated form promyelocyte (rt. lower) and several more mature myeloid cells. The field also contains erythroid elements.

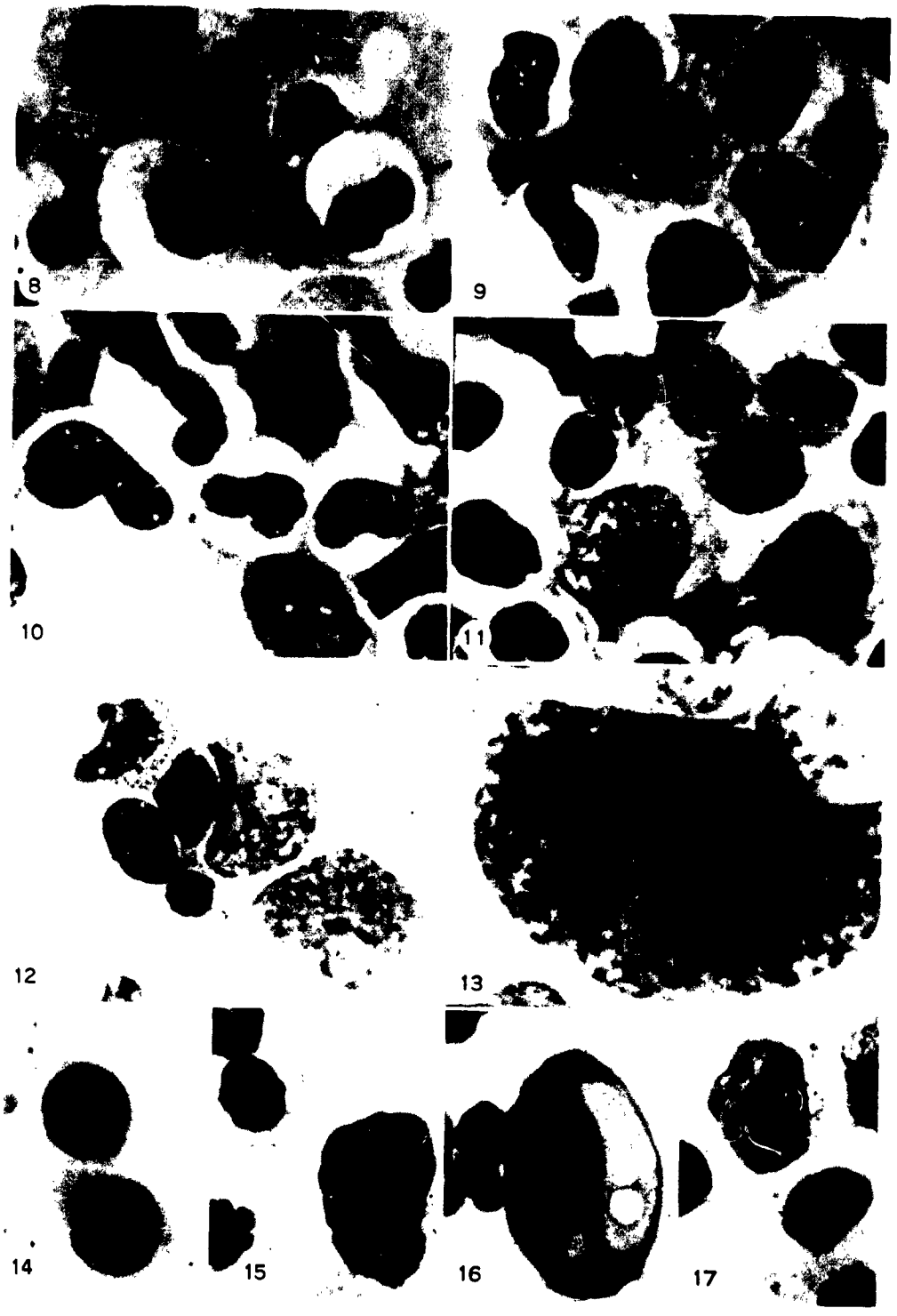
Fig. 6.12 This field represents the contrasting and typical appearance of the neutrophilic metamyelocyte and eosinophilic leukocyte. Pale immature nuclei which are somewhat distorted, are not classifiable.

Fig. 6.13 Mature megakaryocyte.

Fig. 6.14 A type of lymphocyte frequently encountered in the pig in bone marrow and peripheral blood.

Fig. 6.15 An RE cell of the histiocytic type.

Fig. 6.16 Hyperchromatic nucleus with vacuolar inclusions. Speculation links this form with viral entities. This is included as is Fig. 6.17 as an example of abnormal forms encountered in a field control series.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SPLENIC CHANGES IN SWINE EXPOSED TO SUPRALETHAL DOSE OF IONIZING RADIATIONS. (LD 100 in 2 to 6 DAYS)

Fig. 6.18 All that remains from a lymphoid follicle is a peripheral layer of partially phagocyted cell debris and central arteriole surrounded by "epithelioid" cells. The remnant of lymphatic follicle is encircled by hemorrhagic red pulp. 400X.

Fig. 6.19 The central "epithelioid" cell mass of a lymphatic follicle contains some macrophages. The majority of cells are identified as distorted or degenerating reticulum cells. 700X.

Fig. 6.20 All smaller cells in this area have pyknotic nuclei and pale, indistinct cytoplasm. There is in right lower corner a spindle-shaped polygonal basophilic cell containing ovoid nucleus with clumped dark chromatin representing an RE-cell from a periarteriolar sheet, and comparable to the cell structures seen in the upper left of Fig. 6.18. 1300X.

Fig. 6.21 These cells bear essential characteristics of injured and degenerated reticulum cells, and are comparable both by position and appearance with the cells in Fig. 6.19. 1300X.

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SPLEEN HISTOLOGY AND CYTOLOGY IN SWINE EXPOSED TO LD 100 in 7 to 14 DAYS

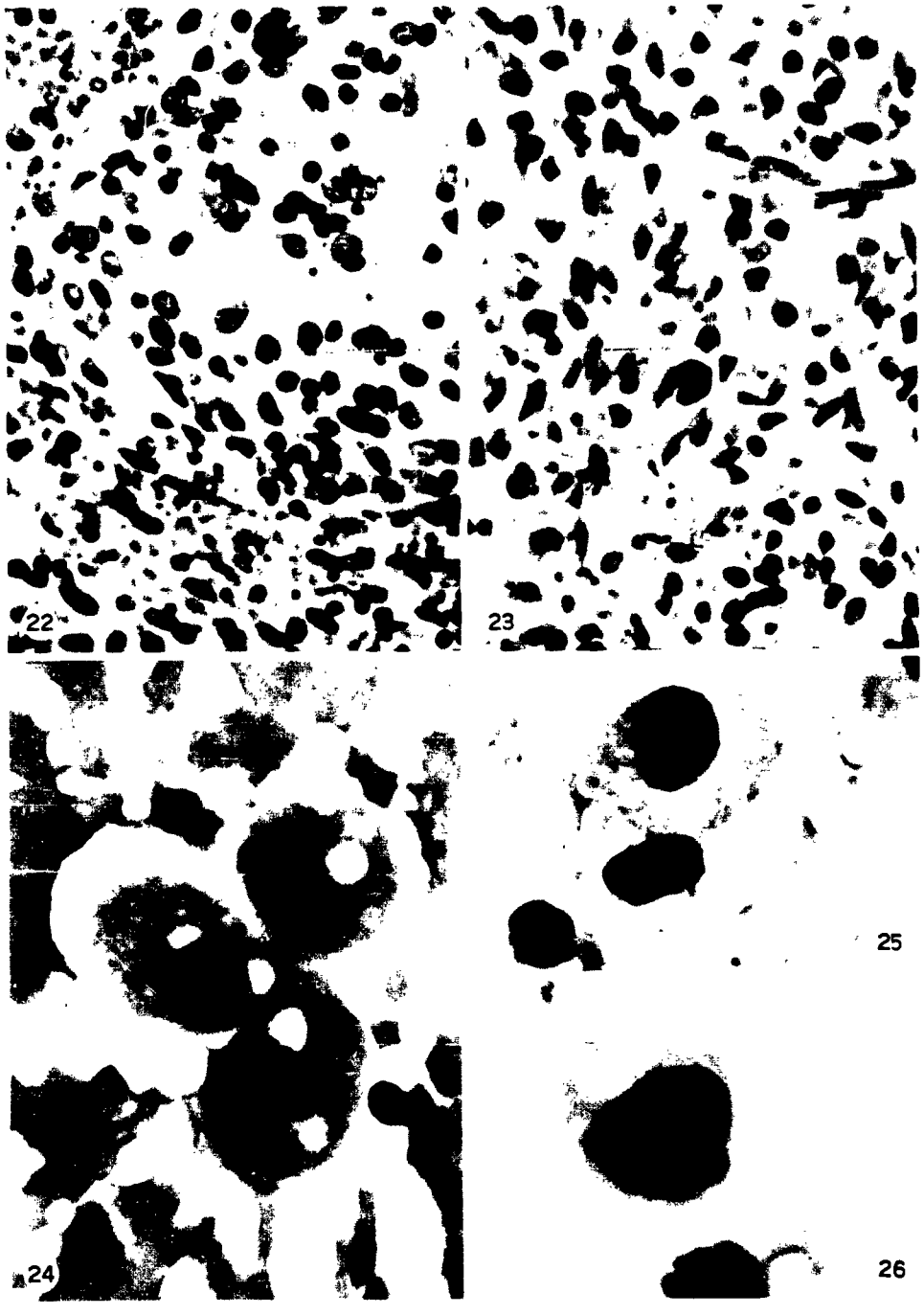
Fig. 6.22 The lymphatic follicle contains some pyknotic lymphocytes interspersed between cells with ill-defined cytoplasmic borders and with conspicuous ovoid nuclei. Note in the center a relatively large ovoid cell having eccentrically located vesicular nucleus and a large amount of pale cytoplasm. 400X.

Fig. 6.23 Splenic red pulp in animals dying on/about the seventh day after exposure does not contain recognizable lymphoid and blood cells, except for a few erythrocytes within an outside of sinuses. There are numerous prominent, intact, large nuclei. These nuclei are atypical, belonging to reticulum cells at various levels or injury and recovery. 400X.

Fig. 6.24 Group of ovoid cells comparable morphologically to the cells seen in the center of Fig. 6.22. The cytoplasm contains large vacuoles and pale nucleus which has almost nonspecific distribution of chromatin. These cells are phagocytic reticulum cells classified as macrophages. The content of cytoplasmic vacuoles was not identifiable by microscopy. 1300X.

Fig. 6.25 Despite anomalous staining - facilitated by field conditions - the stippling of nucleus and appearance of true nucleolus is considered indicative of proliferative activity in atypical stem cell of lymphocytic characteristics. 1300X.

Fig. 6.26 Tinctorial affinity as well as peculiar yet almost orderly clumping of chromatin in this cell is interpreted as a sign of imminent proliferative activity. This cell is considered atypical, but not dying reticulum cell from red pulp at dose and time comparable to that indicated in Fig. 6.23. 1300X.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HISTOLOGIC AND CYTOLOGIC PATTERN ENCOUNTERED IN SPLEEN OF ANIMALS DYING ON OR ABOUT 14 DAYS

Fig. 6.27 Lymphatic follicles in form of a rounded mass containing packed reticulum cells of various shapes. Note absence of mature lymphocytes. Layer of elongated, closely packed, spindle-shaped cells surrounds the follicle. 400X.

Fig. 6.28 The red pulp is at this time the site of considerable mitotic activity. Many cells possess hyperchromatic nuclei. Two arterioles shown here are devoid of follicular grouping which normally contains lymphoid tissue. 450X.

Fig. 6.29 The spleen imprint demonstrates large cells belonging to the category of RE cells but not easily classifiable as to the type. Note marked changes in chromatin pattern as well as very indistinct cytoplasm. 1300X.

Fig. 6.30 Cells with deeply basophilic nucleus and clumped chromatin are shown here. Note nuclear and cytoplasmic basophilia. These cells represent atypical stem cells probably belonging to lymphocytic series. 1300X.

Fig. 6.31 Plasma cells and "plasmacytoid" cells were numerous in lymphatic follicles as well as in the red pulp from 14 days after detonation. These cells were found to be especially numerous in spleens morphologically similar to those shown in Figs. 6.32 and 6.33. 1300X.


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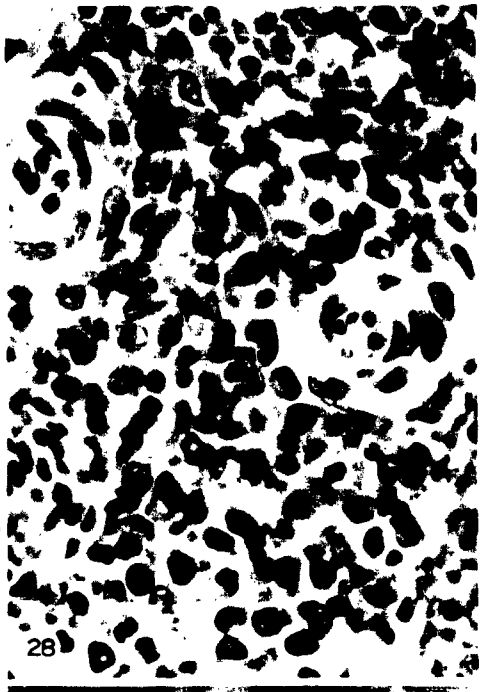
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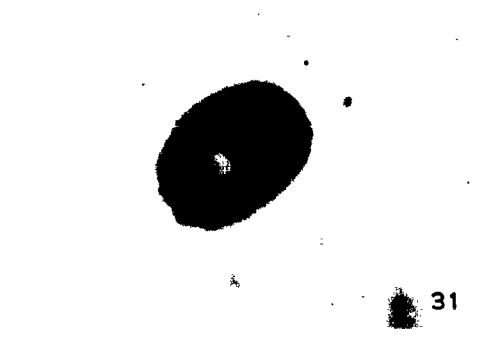
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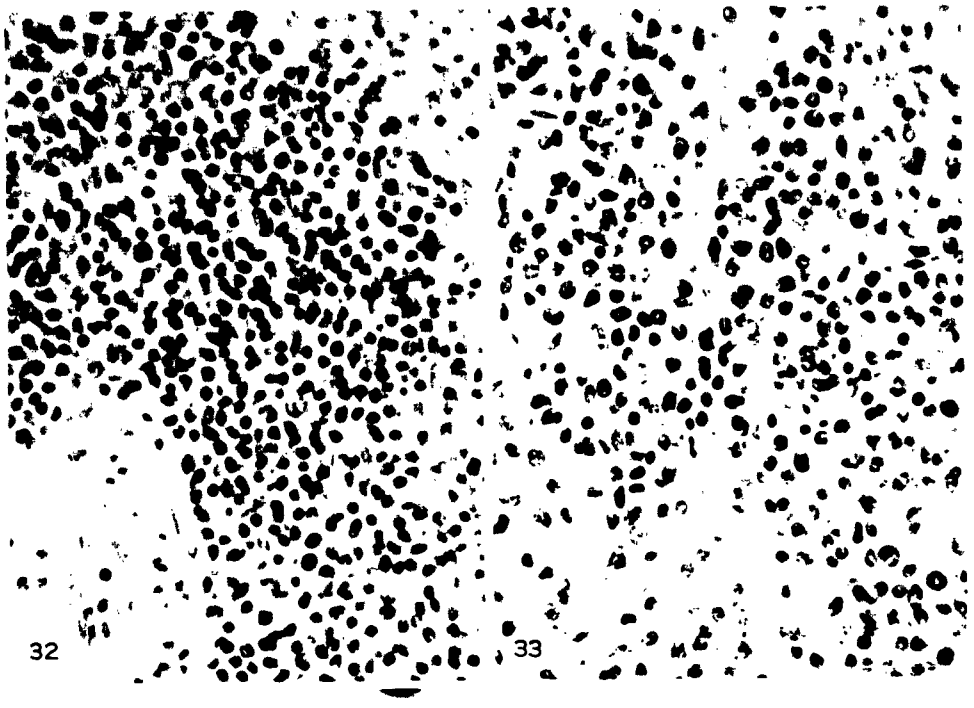
LYMPHOID REGENERATION IN SPLEEN OF SWINE FROM GROUP III (LD 100 in 14 to 30 DAYS)

Fig. 6.32 Spleen area representing a well-populated lymphatic follicle with thickened arteriole. Majority of nuclei are rounded, deep blue and lymphoid in character. Note recent hemorrhage at the periphery of follicle. 200X.

Fig. 6.33 Hemorrhagic red pulp contains many reticulum cells and plasmacytoid cells, but few nucleated blood cells. 250X.

Fig. 6.34 A group of small round basophilic cells resembling mature hyperchromatic lymphocytes. Homogeneous appearance of nuclei, peculiar tinge of blue cytoplasm as well as irregular shape of nuclei in cells pertain to inherent changes in lymphocytic cells prior to death. This pattern is apparently made prominent and somewhat artificial in field preparation of stained imprints. Compare with lymphocytic cells in Figs. 6.4 and 6.5. 1300X.

Fig. 6.35 Binucleated large cell from the red pulp. The ambivalent staining characteristic of the cytoplasm is interpreted as an evidence of degenerative process. Note micro-organisms in close vicinity. 1300X.



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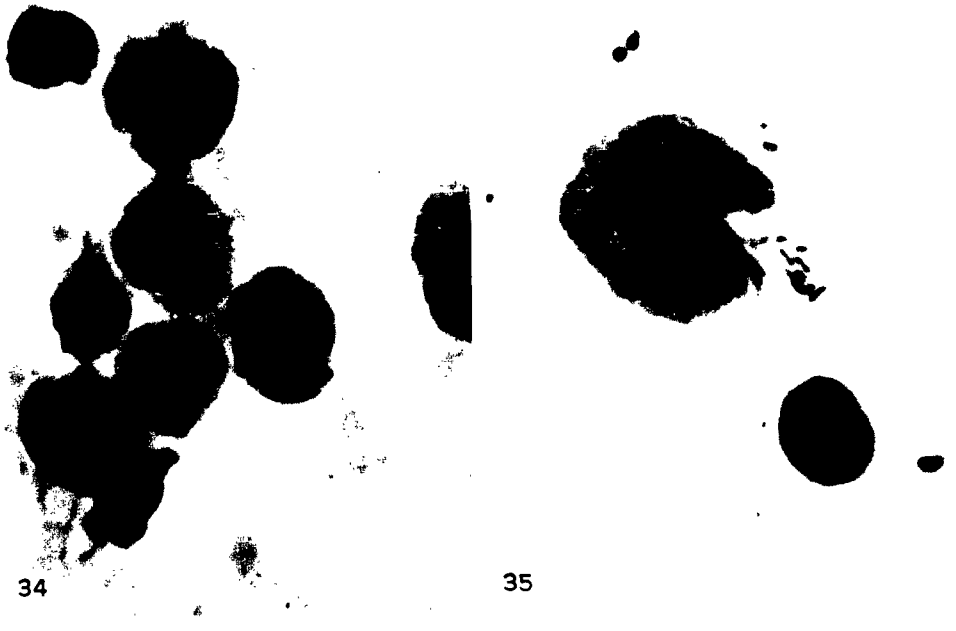

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Analyzed by: _____ Date: _____

Evaluated by: _____ Date: _____ Animal No.: _____

Clinical & Experimental: Total 500 cells counted in human spleen imprints.

	%		
1. Lymphocyte Mature Small		(71)*	
2. Ly-cyte Young & Mat. Large			Total Thromb.
3. Polymorph. Segm. Neutro		(25)	Total Stem
4. Eosino		(1.5)	Total Lympho
5. Baso		(1)	Total Myelo
6. Metamyelocyte & Band		(7)	Total White
7. Plasma Cell Mature		(4)	Total Erythro
8. Monocytes		(8)	Total RE
Megakaryocyte			
Stem Cell (Blasts)		(5)	
Germinal Center Cell			
Promyelocyte			
Myelocyte		(0.1)	
Pronormoblast			
Retic. Cell Diff. w/Phago. R. E.		(0.5)	
Pulp Cell			
Nucleated RBC (Normoblasts)		(0.5)	
Phagocyte (not determined orig.)		(±)	
RBC's one + to 4 +			
Disintegrating Myeloid			
Lymphoid			
Erythroid			
Non-Class			
Atypical Forms: Stem			
Myelo			
Lympho			
Erythro			
Non-Class.			
Non-Classifiable Normal			

PAP

FEUL

SEC

Evaluation:

* Numbers in parentheses indicate upper limit of range found in human splenograms.

Figure 6.36 Splenogram sheet.

Chapter 7

WOUND ANALYSIS

7.1 OBJECTIVES

This part of the experiment had five primary and two secondary objectives. The primary objectives were to: (1) observe and document the types, degree, and anatomical distribution of injuries sustained by a selected biological specimen (swine) when exposed to a nuclear detonation in order that the results from single or combined weapon effects could be noted; (2) correlate observed injuries with distance and environment in order that the influence of these parameters could be established; (3) compare rapid field medical impressions with subsequent surgical and pathological findings in order that the merit of initial diagnostic evaluation could be appraised; (4) correlate external observable injuries with subsequently exposed internal injuries or other abnormalities in order that the probabilities of associating certain internal derangements with known external wounding or exposure could be established; and (5) determine the injuries causing physical ineffectiveness based on early medical field observations versus primary cause of death as described by the pathologists.

The secondary objectives were to: (1) identify medical problem areas requiring further experimental exploration and (2) enhance instructional tools pertaining to casualty care through photographing wounds from a nuclear detonation and the attendant medical operations in order that more realism in teaching can be achieved.

7.2 BACKGROUND

There presently exists a paucity of data based on field experimentation that allows for translation into clinically identifiable injuries in man. This resulted from the type of biological specimen used in some cases, the laboratory methods of investigation employed, and considerations of injury from a single weapon effect rather than from combined effects. There also is the fact that current military medical planning factors are based primarily on experiences with injuries sustained from conventional warfare. These factors do not reflect the differences expected both in mechanical and burn injuries from a nuclear detonation as contrasted with conventional warfare. They also fail to account for the additive insult imposed by ionizing radiation. Some estimates of nuclear weapon casualties have been predicated on the observed damage to inanimate objects and then in turn extrapolated for casualty prediction to a living biological specimen, man.

Whereas certain aspects of animal wounding have been accomplished in the laboratory in an effort to simulate field conditions, the correlation of cause to effect has suffered because of the uncertainty of the relationship between the laboratory and field measurements of the injurious agents. Field tests allowed for physical measurements of actual weapon effects and the production of identifiable injuries. This, then, permits return to the laboratory to reproduce and further study the kind and amount of

injuries as produced in the field by going from effect to cause rather than from cause to effect.

Of significant military medical interest is the definition of the word "casualty" in terms of effectiveness as opposed to ineffectiveness. This definition requires the establishment of bases for medical criteria to determine clinical and physical effectiveness as influenced by trauma. These bases require knowledge as to the types and extent of the physical injuries resulting from a nuclear detonation. Past tests were carried out with either small animals or inadequate numbers of large animals and precluded extrapolation to man with any degree of confidence.

7.3 THEORY

The ultimate objective of this medical study was to understand the cause and course of injury in man for purposes of prevention and/or treatment. This type of experimentation in man was morally undesired and therefore a suitable animal that would yield reasonable interim extrapolations to man was needed. The swine was selected (Chapter 1).

In view of the relatively fixed relations of the various effects in the given test shot, certain compromises were inescapable in order to achieve clinically definable injuries. For instance, to produce certain mechanical injuries where the maximum peak overpressure was 6.1 psi, a lethal radiation dose of approximately 615 rep had to be accepted. These compromises did not militate against studying the type of injuries of interest but clearly negated any efforts of determining survival care. As another example, a predominance of glass-missile injury had to be accepted to ensure wounding at those distances where reasonable survival from ionizing radiation could be assured (Appendix B). While the types and incidence of mechanical injury under these circumstances might be biased because of the predominant glass missile, the degree, extent, and distribution of thermal or radiation injury would not be affected.

In clinical experience with human injury and even in laboratory studies of animal injury, it is not possible to evaluate realistically the rapid field diagnostic procedures necessary in the mass casualty situation. This field experiment afforded an ideal situation for comparative evaluation of rapid clinical appraisal against the more refined hospital diagnostic procedures applied to the same injuries. The need for rapid clinical estimation was demanded in this experiment by the urgency for early evacuation of the survival-care animals.

While it was plain that the external mechanical and burn injuries could be observed readily and rapidly, even in the field, it was equally plain that internal injuries and somewhat delayed radiation sickness could not be observed and evaluated during the early recovery period. However, it was necessary to consider and appraise the later effects of early undeterminable injuries. This kind of information would be most helpful to the surgeon in deciding the care and prognosis of the casualty. In order to provide the surgeon with this guidance, the observable external injuries were surgically pursued to determine the full extent of involvement of internal or deep organs or structures. Ionizing radiation injury was also given due clinical weight based on the device yield, distance from ground zero, and degree of shielding. The presence of the three weapon effects as injury-producing agents afforded an opportunity for studying more completely the total-body insult which might result from a nuclear detonation under a given set of circumstances.

7.4 SHOT PARTICIPATION

This experiment was conducted during Shot Priscilla, with 719 animals. Documentation procedures were given a trial run on 40 animals during Shot Wilson (Appendix A), but the results are not included in this analysis.

7.5 OPERATIONS

Written and photographic data was collected for each station before and after placement of the animals. Following the detonation, wound-analysis teams were released initially into the areas under Rad-Safe control. These teams described specific injuries and recorded other data, such as displacement or general condition of the animals. Black-and-white and color photographs of the wounds were taken to supplement the written records. Following documentation, the animals were removed to surgery, pathology, or the pens as appropriate.

The 719 animals were placed at the eleven stations shown in Table 7.1. In addition, four were placed in conjunction with CETG Project 33.4, and five in machine-gun emplacements (Chapter 8). Documentation was accomplished by seven wound-analysis teams, plus one supervisory team. Each team was comprised of one officer and one photographer, supplemented by the animal retrievers and holders.

The main effort was directed initially to wound analysis at Stations 6 through 9. This was done in order to expedite the evacuation of selected animals to the Surgical Section for early treatment. Following the clearing of these selected animals, documentation was completed for the remaining animals at these stations plus Stations 10 and 11.

Observation on animals in Stations 1 through 5 was delayed until 3 hours after detonation, pending Rad-Safe release. This delay was anticipated and did not interfere with the programed plan for wound analysis.

In the interest of evaluating special features of wound production at the various stations, emphasis was placed on accumulating supporting data for the following: translation of animals, Stations 1 and 2; translation of animals and certain battlefield equipment, Stations 3, 4, and 5; and generation of glass missiles, Stations 6 through 9. Stations 10 and 11 had no special environmental consideration. All station populations were observed for thermal injury.

Followup wound-analysis data was collected subsequently from the recordings of the respective divisions of the Professional Section (Chapter 3).

7.6 INSTRUMENTATION

In general, wound-analysis instrumentation consisted of observation, recording, IBM coding, and photography. Observations fell into two categories: (1) early clinical descriptions in the strike area, and (2) refined measurements in the hospital area. The former was recorded on a special tag (Figure 7.1), and the latter was noted on individual records of the interested supporting professional groups. The original copy of the field tag was submitted by the officer in charge of each wound-analysis team to the records-control officer prior to clearing the strike area. The duplicate tag accompanied the wounded animal to the next medical echelon.

Photographic recording consisted of motion and still photography taken before and after the detonation. Motion pictures were made to show the operational flow of the medical support activities incident to casualty care. Special environmental conditions

were also photographed as preshot data (Figures 7.2 and 7.3). Postshot photography generally included station population appearances (Figures 7.4 and 7.5) and special missile or animal translational subjects. In addition, corroborative photographs of recorded wounds were taken both in the strike area and in the hospital area.

7.7 RESULTS

It is emphasized that the presented results cannot be evaluated without taking into account the possibility of both human and mechanical error inherent to the very nature of the operation. Error and bias stemmed from the following: (1) documentation of individual observations under unusual and adverse physical conditions during the recovery period (radiological safety devices and prevailing heat and dust); (2) differences of clinical opinions by a successive line of observers at significantly different times at which the animals were observed, and (3) interpretation of data as record content was reduced to work sheets prior to machine recording for quantitative tabulation.

The results which follow were confined to Shot Priscilla and were based on the number of records containing data rather than the number of animals placed at risk at any station.

7.7.1 Injury versus Distance. At attempt was made first to gain an overall picture of the types of injury sustained as a function of increasing distance from ground zero, starting outside the precursor (Table 7. 2).

In general the following were noted: (1) Most animals suffered injuries due to combinations of the weapon effects rather than from any single effect. (2) There was a low incidence of mechanical injuries (Table 7.3) at Stations 4 and 5, due to the lack of overpressures necessary to create missiles of the simulated battlefield equipment (Figures 7.2 and 7.4). (3) There was a sharp increase of mechanical injuries at Stations 6, 7, and 8, despite their greater distance from ground zero than the simulated battlefield stations. This was due to the introduction of an artificial environment where the entire front wall of pens consisted of glass panels (Figures 7.3 and 7.5). (4) Burns were recorded at all stations except 11. A relatively high number of animals at Stations 7 and 8 were not reported as having observable thermal injuries during the early hours of recovery. Of the animals recorded, over 90 percent sustained burns at Station 9 and about 25 percent at Station 10, showing a decreased incidence with distance. (5) The animals exposed at Stations 1 through 9 manifested ionizing radiation injury varying from lethality to subclinical findings. The percentage of animals at any given station sustaining clinically reported radiation injury followed the pattern of decreasing incidence with distance, ranging from over 90 percent at Station 4 to approximately 28 percent at Station 8.

7.7.2 Extent and Body Distribution of Injury. The analysis of the extent of injuries was confined to observable mechanical and thermal wounds. The mechanical injuries sustained ranged from complete dismemberment to simple abrasions. Dismemberment occurred only within the precursor area where about 75 percent and 50 percent of the animals at Stations 1 and 2 respectively were thus involved (Table 7.4). Representative types of dismemberment are shown in Figures 7.6, 7.7, and 7.8. Avulsion of soft tissue was also seen (Figure 7.9).

Of the animals outside the precursor whose records contained documentation of mechanical injuries, the following patterns were noted: (1) No significant numbers of injuries occured at Stations 4 and 5. (2) A predominance of lacerating wounds, most of which were multiple, were found in the forward glass-environment stations (Figures 7.10

and 7.11). (3) Penetrating wounds which included puncture-type wounds of both the extremities and the thoracic and abdominal cavities were also reported at these glass-inclosed stations (Figures 7.12, 7.13, and 7.14). They primarily were single events in contradistinction to the lacerations previously mentioned (Figure 7.15). (4) Through-and-through perforating wounds were not reported. (5) Fractures of both the open and closed type were not documented in significant numbers (Table 7.5).

Data on extent of burn injuries (Table 7.6) revealed the following: (1) The majority of animals located outside the precursor sustained burns of 20 percent or less of body surface (Figure 7.16). (2) About 20 percent of the animals were described as having burns greater than 40 percent of body surface (Figure 7.17), with a few greater than 60 percent. (Animals were unshaven.) (3) Three animals were recorded as having burns of the tongue (Figure 7.18).

Analysis of wound distribution data indicated that, generally, the incidence of involvement of any body part paralleled the percent of the total body which that part represented (Table 7.7).

7.7.3 Types of Injuries Due to Translation or Secondary Missiles. Significant displacement of animals and equipment were noted only within the precursor. The injuries resulting from animal displacement varied from complete dismemberment to fractures as previously described. The former occurred predominantly at Stations 1 and 2 where the displacement was greatest (Table 7.8). Dismemberment also occurred in a few animals that were subjected to severe impact upon sudden deceleration because of striking a fixed object, though not significantly displaced in distance (Figure 7.19). At Station 3, 24 penetrating and lacerating wounds and 12 fractures of long bones were observed. Field equipment was significantly displaced within the precursor. A filled water can weighing 52 pounds was thrown about 375 feet from the point of original placement and a 33-pound machine gun was displaced 230 feet. With one exception, no animal injuries in this area could be directly ascribed to these missiles. The exception was one casualty where a small can was translated with enough force to produce a tunneling-type wound within the abdominal wall without entering the abdominal cavity (Figure 7.20).

Outside of the precursor, secondary missile injuries were due to the fragments of glass (Appendix B) which were generated from the glass panel structure at the stations. The glass missiles produced an adequate number of superficial wounds but much fewer than predicted of the penetrating abdominal and thoracic wounds. Some of these injuries resulted in bowel evisceration (Figure 7.14) and others caused internal injuries (Figure 7.21).

7.7.4 Comparison of Field Estimates of Extent of Burns versus Hospital or Necropsy Estimates. A comparison between the initial field estimates and the later hospital or necropsy estimates of the percentage of body surface burn revealed agreement within ± 10 percent in about three-fourths of the burns reported (Table 7.9). The remaining difference primarily fell within ± 30 percent.

7.7.5 Observable Injury versus Cause of Death. Four hundred and ninety-four field observations were compared to 306 autopsy reports (Table 7.10). Mechanical and burn injuries were observed as early clinically identifiable entities in the field, with radiation injury emerging with time as the primary cause of death.

7.7.6 Time of Death. The data revealed that: (1) of the animals placed inside the

precursor about 90 percent died within a few hours after injury, (2) relatively few animals through Station 7 survived, and (3) a significant number of animals from Station 8 and outward survived beyond the eleventh day (Table 7.11).

7.7.7 Influence of Combined Injuries. The time of death was determined for 292 animals injured by various weapon effects (Table 7.12). The periods of death were categorized as the first 5 days, 6 to 12 days, and 12 to 29 days. Injuries of various combinations appeared to have little influence on time of death. The apparent increased survival time in the mechanical injury group is discussed elsewhere. In the 101 animals where the extent of body surface burn was correlated with mean day of death due to ionizing radiation, the trend showed the length of survival time was inversely proportional to the size of the area burned (Table 7.13 and Figure 3.12).

7.8 DISCUSSION

Because of similar findings at Stations 2 and 3, and Stations 4 and 5, respectively, they were considered as two paired stations rather than as separate sites. The burn data from Station 9 was considered inadequate and was deleted in the burn analysis. In addition, at other stations, for reasons stated previously, analysis was confined to those animals whose records were documented adequately. This fact limited interpretation of findings to the documented animals and did not reflect the incidence of a given injury in the total populations exposed. The data was analyzed within these imposed limitations and in conformity with the objectives as initially stated.

Mechanical, thermal, and radiation injuries were found at all stations except 11, at which none were noted. The total trauma picture portrayed those injuries observed early by the field examiners, as well as those which were manifested later and were described by either the surgeons or pathologists in the hospital area.

Within the precursor area, mechanical injury was noted as the predominant type in the majority of the casualties reported by both the field observers and pathologists.

With the exception of the single animals in foxholes at Stations 2 and 3, there were only 8 animals (at Station 5) that were reported to have sustained radiation injury alone; all others followed the pattern of combined injuries (Table 7.2).

In view of the thermal flux at Station 5, it is difficult to explain how any of these exposed animals reportedly escaped thermal injury. The reason may lie in human error of observation, notation, coding, or record manipulation.

It was of interest to note that about one-fourth and one-half of the casualties at Stations 7 and 8 respectively were reported as having mechanical and radiation injuries without burns. It is conceivable that huddling of animals at these stations might have afforded some momentary shielding from the thermal pulse followed by reorientation prior to the arrival of the blast wave. On the other hand, the thermal injuries might have escaped observation if relatively small body surfaces were involved, especially in pigmented animals or those whose burns were obscured by dust (Figure 7.22).

Thermal and ionizing radiation injuries, with and without mechanical wounds, were the predominat combination.

The mechanical injuries at Stations 1, 2, and 3, located within the precursor region, varied from unidentifiable animals parts to partial dismemberments. At Stations 6 through 9, mechanical injuries were described in about 60 percent of the population placed at risk (Table 7.3). This incidence must be considered in light of the glass-missile environment.

The same artificial environment probably accounted for the high occurrence of lacerations with a somewhat lower number of penetrations and relatively few fractures.

Thermal injuries were observed in the animals as far away from ground zero as Station 10. Within the precursor, burns were described in 11 out of 39 field observations. Theoretically, all of the exposed animals at these stations should have received thermal wounds. This apparent discrepancy may be accounted for because the field observers were determining the wounds that they felt were the main cause of ineffectiveness and did not concern themselves primarily with contributing injuries. In addition, burned areas were not readily discernible in some animals because of generous coatings of desert floor dust. In some observations the dismemberment and evisceration understandably took precedence over the less dramatic burn injuries. The two animals that were in foxholes escaped the thermal effects.

Three hundred and sixty animals, excluding those at Stations 1, 2, 3, and 9, had sufficiently well-documented clinical records to allow analysis as to the percent of body surface burned. At Stations 4, 5, 6, 7, 8, and 10, records reflected burns in about 78, 94, 75, 40, and 27 percent, respectively, of the animals originally placed at these sites. It was felt that this number of records could be considered as representative of the burn-injury picture. Of the total reported animals, about 66 percent sustained burns involving 20 percent or less of the body surface; 19 percent involved 21 to 40 percent body surface; 13 percent involved 41 to 60 percent body surface, and 2 percent involved greater than 60 percent body surface. Under the prevailing conditions no early clinical differentiation could be made between second and third degree burns.

An attempt was made to get reasonable uniformity in the assessment of burned areas by the use of previously prepared templates. Estimates that were greater than 50 percent of body surface involvement were somewhat surprising. In view of the fact that nearly all of these fell within the 60 percent limit, it was felt that human error might be responsible for this overestimation. Also, in view of photographic evidence of sudden vigorous response of the animals to the thermal pulse, one might speculate that the skin could have momentarily contracted toward the burning source thereby exposing greater than 50 percent of the body surface to the incident thermal pulse. The possibility of sudden partial twisting of the body toward the stimulus with more body surface presentation was considered improbable because of the time of delivery of the effective thermal pulse. Internal body burn involvement was recorded in three animals but was limited to the tongue. No burns of the tracheobronchial tree were described.

In order to study the broad picture of the body parts involved in wounding, suitable descriptive records of animals exposed to prepositioned missiles, both battlefield debris and glass, were analyzed. Considerations pertaining to part involvement also included thermal injuries in these animals except at Station 9. This analysis embraced 310 animals located at Station 4 through Station 10. Discrepancies between the number of wounds per body part (Table 7.7) and types of wounds (Table 7.10) were due to the fact that the records used in the latter table contained a single type of injury diagnosis but in some cases failed to locate the injury. In general, it was found that the incidence of involvement of any given body part followed the normal percent body surface contributed by that part. The abdomen (and rump) had the highest incidence followed by the thorax, head, and neck, and lastly the extremities.

After examination of the data as to the types of mechanical trauma, attention was turned next to etiology of these wounds. Injury due to missiles was regarded from the viewpoint of the body being translated as a missile as well as the body acting as the recipient of secondary missiles generated from the environment. Translation of the

animals occurred within the precursor area only. Some animals were translated only about 10 feet and yet sustained lethal injuries upon impact with the wire fence and supporting posts. The majority of identifiable animals at Station 1 and 2 were thrown distances greater than 150 feet. An attempt was made to rule out the probability of animals walking from the point of initial landing to where later found at time of recovery. This was done by graphically plotting the points where the animals were found. Arcs were then drawn through these points and only those animals who fell reasonably close to the arcs were counted, provided they originated from the same station. In other animals, any doubt of subsequent movement after impact was eliminated by the unquestionable incapacitating dismemberment. Outside of the precursor region, where animal translation was not found, mechanical injuries were not caused by flying debris except at Stations 6 through 9 where glass missiles were produced. At Stations 4 and 5 the battlefield equipment was moved only a few fect and did not produce casualties. However, one penetrating injury was sustained when an animal was hit by a small fruit juice can that was in the area by chance. Nearly all the other recorded mechanical injuries occurred in Stations 6 through 9 and were due to the glass missiles generated in these stations. These missiles were most commonly described as being a few inches long, 1 to 2 inches wide, and irregular in shape. It was felt that if Stations 6 through 9 had been similar to the battlefield-simulated environment at Stations 4 and 5 essentially no significant mechanical injuries, excepting possibly fractures, would have occurred. The glass station environment afforded an opportunity for generating mechanical injuries for other experimental studies.

In light of impressions noted by clinicians that on many occasions there is a tendency to overestimate burn areas in the initial examination of patients, it was felt worthwhile to compare hasty field estimations of burns with later and more refined observations in the hospital. Officers inexperienced in estimating burns on the test animal received a rather brief indoctrination in this procedure based on the use of certain anatomical landmarks and templates. It was found that the estimates of total burned areas under field conditions correlated very well with those done later and more precisely by different examiners at the hospital area.

A similar attempt was made to compare the observations on the extent of mechanical injuries noted in the field with those made later at the hospital but this was not possible (Chapter 3). With the exception of the dismembering injuries, field data lacked the preciseness to warrant any reasonable comparisons with surgical or necropsy reports. Internal injury and external findings could not be correlated on a general basis. This was due to the predominantly special glass missile which produced a cutting type of missile path. The evisceration found in many of the animals was caused by the animal's post-detonation movement, grunting, and exteriorizing the bowel through incision-type wounds rather than loss of the containing abdominal wall. Penetrations into the thorax and abdomen were determined easily in the field by competently trained observers.

An attempt was made to see if any prognostic credence could be placed on the injuries observed early in the field as compared to the primary cause of death as judged by the pathologists. The field examiners were instructed to evaluate the injuries that in their clinical judgment would have caused physical ineffectiveness. This data was compared with the primary cause of death noted in the necropsy reports. It was found that, among the 719 animals placed at risk, 494 were declared as casualties by the field examiners. Field observers reported mechanical injuries as dominant within the precursor whereas outside the precursor both mechanical injuries and burns were reported. In some instances ineffectiveness due to burns also was recorded for some animals within the

precursor area. Exclusive of the animals placed in the foxholes at Stations 2 and 3, the clinical syndrome of ionizing radiation was not described during the early recovery period (first hour). The pathologists' reports showed a significant number of deaths due to radiation injury in the animals located from Stations 4 to 7, inclusive. Their reports showed a commensurate drop in the burns and mechanical injuries as the primary cause of death in all stations outside the precursor. This was in contrast with the early field observations that reflected mechanical and thermal injuries primarily and that were made before the manifestation of a clearly defined radiation syndrome. (It should be remembered that in some instances there was not a direct comparison of serial records on the same animals.) Nevertheless, it was felt that there was sufficient comparable data from Stations 4 through 7 to demonstrate, in general, that the clinically incapacitating injuries observed in the field within a few hours after injury were not the main causes of death.

In view of the lower doses of ionizing radiation necessary to produce an LD_{50} in animals injured by the combined weapon effects as compared to those sustaining only ionizing injury (Shot Wilson), the data was reviewed to determine the influence of combined injuries. A teeter point was sought, based on the types of combined injuries and extent of injury. The time of death rather than death itself was used as the criterion, because those animals that were of interest died within 30 days. When various combinations of weapon effect injury were studied in the animals that died in 4 days, the paradox developed that a lesser percentage of animals died from combined blast, burn, and ionizing injuries than those with radiation alone or in combination with burns. This can be explained by the results at the glass-environment stations. These were located at a greater distance from ground zero than some of the stations at which greater thermal and nuclear radiation fluxes existed but at which the environment was not conducive to missile production. In those animals that died within 5 to 12 days, there was essentially no difference in the various combinations of injurious agents. In this period, ionizing radiation injuries alone accounted for 46 percent, whereas the combination of blast, burn, and ionizing effects in the same animals were responsible for 62 percent of the deaths. From the thirteenth to the thirtieth day, about 6 percent of the animals died from the various weapon effects, except those that sustained combined mechanical and ionizing injuries. In this latter group the percentage rose to 27 percent. This was biased by the paucity of burn data reported from Station 9.

Attempts to relate the extent of injury to the time of death were confined to the correlation of the percent of body surface burned in animals in which the cause of death was ionizing radiation. The dose of ionizing radiation was considered comparable for the animals studied at any given station (Table 7.13). In general it was noted that there was a decreased survival time in animals with an increased percent of body surface burned. However, no conclusions could be made as to the influence of percent of body surface burned on the time of death in these irradiated animals. This was due to the fact that few animals were available for study at the given points.

Collation of the data in this chapter revealed that information could be taken only from the records that were complete. The number of records meeting this requirement did not equal the number of animals placed at any given station. Many factors contributed to this situation. One of the most critical was the apparent decrease in physical endurance of the field observers under the prevailing conditions of the recovery period. It was one thing to document injuries under idealized conditions of a medical facility and quite another when attired in Rad-Safe clothing and operating in intense heat and in the field. It was of interest to note the increasing brevity of the reports as the recovery operation

continued. Even in the presence of excellent motivation, the degree of clinical acumen and attention to detail appeared to be very sensitive to the degree of physical exhaustion. Another important factor was the successive observations made by different observers on what was thought to be the same animal. Identifying tags on the animals in many cases did not lend themselves readily to certain and rapid recognition especially in the field. Variations in judgment, interpretation, and human error also entered the picture. The use of the case method wherein specified observers remain responsible for specified animals throughout the entire operation, instead of the multiplicity of observers as used, would minimize some of the aforementioned undesired features. The case method would enhance the extremely important aspects of control, responsibility, and personal interest.

Photographic recording included subjects of medical interest embracing preparatory procedures, documentation of types of injuries, and supporting medical operations in the strike area and in the treatment and laboratory areas. Coverage included motion picture and still photography. Still photographs included both color and black-and-white photographs, examples of which are shown in this report.

7.9 CONCLUSIONS

Clinically identifiable mechanical, thermal, and ionizing injuries in varying combinations and degrees were produced under field test conditions.

Ionizing radiation was the decisive injurious agent in nearly all casualties that did not die prior to or soon after recovery, in this particular experiment with this nuclear device.

Mechanical injury production was a function of distance and environment with early death-dealing trauma inside the precursor wave area and secondary missile injuries primarily caused by glass missiles outside this zone.

The extent of burns and degree of ionizing radiation sickness diminished as the distances from ground zero increased.

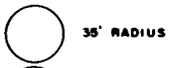
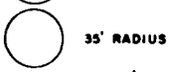
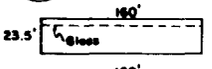
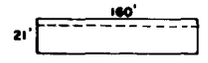
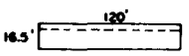
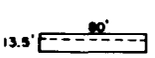
Environmental factors influenced resultant injuries and varied from blast and thermal protection afforded by foxholes to missile-casualty production at the glass-paneled stations. The simulated battlefield environment limited to selected items of equipment did not contribute to casualty production.

Rapid early field medical impressions agreed very well with later estimates of the percent body surface burned.

The time lag between injury and clinical manifestation of radiation sickness precluded early diagnosis by field observers and thereby denied correlation between the early field and later hospital and/or necropsy findings as they might pertain to onset of incapacitation or ultimate fate (except in certain critical mechanical injuries).

Experimental design for similar future field tests must be acutely sensitive to human response under unusual conditions.

TABLE 7.1 ANIMAL PLACEMENT AND BLAST, THERMAL, AND RADIATION MEASUREMENTS, SHOT PRISCILLA

Station Number	Enclosure	Distance from Ground Zero	Number of Animals	Glass Missiles	Battlefield Debris	Maximum Peak Overpressure	Peak Dynamic Overpressure	Thermal Exposure	Gamma (Air)	Neutron (Air)
		ft				psi	psi	cal/cm²	rep	rep
1*		2,630	20	No	No	10.0	26.3	85	12,100	8,700
2*		2,730	20	No	No	9.9	22.0	82	10,200	7,200
3†		3,000	40	No	Yes	9.8	13.0	75	6,500	4,290
4†		3,930	40	No	Yes	9.2	1.9	53	1,490	770
5†		4,150	40	No	Yes	8.5	1.4	49	1,070	525
6‡		4,430	145	Yes	No	7.3	1.1	44	711	323
7‡		4,770	145	Yes	No	6.1	0.76	39	435	180
8‡		5,320	110	Yes	No	4.9	0.48	32	197	71
9‡		6,120	70	Yes	No	3.7	0.26	24	65	19.4
10		7,380	40	No	No	2.4	0.1	15	12.2	4.2
11		9,490	40	No	No	1.4	<0.1	6.9	1.1	0.2

* Details, Figure 10.1
† Details, Figure 10.2
‡ Details, Figures B.1 through B.3

TABLE 7.2 TYPES OF INJURY BY STATION

	Stations							
	4	5	6	7	8	9*	10	11
Physical Effects:								
Peak side-on overpressure (psi)	9.2	8.5	7.3	6.1	4.9	3.7	2.4	1.4
Peak dynamic overpressure (psi)	1.9	1.4	1.1	0.76	0.48	0.26	0.1	<0.1
Thermal flux	53	49	44	39	32	24	15	6.9
Ionizing radiation flux (rep) (gamma and neutron)	2,260	1,595	1,034	615	268	84	16.4	1.3
Type of injury:								
Radiation	—	8	—	—	—	—	—	—
Burn	—	—	—	—	—	—	—	—
Mechanical	—	—	—	—	—	—	—	—
Radiation and burn	35	37	10	35	26	—	12	—
Radiation and mechanical	1	—	5	35	45	26	—	—
Radiation, burn, and mechanical	2	1	91	75	20	—	—	—
Burn and mechanical	—	—	—	—	—	1	—	—

* Data on burns inadequately recorded at this station.

TABLE 7.3 MECHANICAL INJURIES BY STATION, WITH OR WITHOUT OTHER INJURIES

Station	Total Animals Placed	With Mechanical Injuries	
		Number	Percentage
With selected battlefield equipment and debris:			
4	39	3	8
5	40	1	3
With glass as missile source:			
6	145	96	66
7	145	110	76
8	110	65	59

TABLE 7.4 DISMEMBERED AND NONDISMEMBERED ANIMALS

	Stations		
	1	2	3
Animals placed	20	20	40
Dismembered			
Nonidentifiable or inadequately documented	6	2	19
Complete	7	5	1
Partial	1	1	0
Evisceration	1	1	0
Nondismembered	5	11	20

TABLE 7.5 TYPES OF MECHANICAL INJURY BY STATION

Figures are not additive in terms of total number of animals placed or total number injured because some of the same animals sustained several types of injuries.

Station	Abrasions		Lacerations		Penetrations		Perforations		Fractures		Open	Closed
	Single	Multiple	Single	Multiple	Single	Multiple	Single	Multiple	Single	Multiple		
4	—	1	1	—	—	—	—	—	1	—	—	1
5	1	—	—	—	—	—	—	—	—	—	—	—
6	9	3	24	66	27	9	—	—	7	—	3	4
7	15	7	32	64	12	5	—	—	1	1	1	1
8	9	6	34	20	17	4	—	—	3	—	1	2
9	1	—	15	10	6	1	—	—	1	—	—	1
10	—	1	—	1	1	—	—	—	—	—	—	—
11	—	—	—	—	—	—	—	—	—	—	—	—

TABLE 7.6 EXTENT OF BURNS BY STATION

Based on the number of records indicating burn injuries that were sufficiently well documented to derive percentage of body surface burned; Station 9 excluded.

Station	Number of Animals				Percentage of Animals			
	< 20 pct	21 to 40 pct	41 to 60 pct	> 60 pct	< 20 pct	21 to 40 pct	> 41 to 60 pct	> 60 pct
	Body Surface Burned				Body Surface Burned			
4 and 5	29	16	13	4	47	26	21	6
6	75	27	33	1	55	20	24	1
7	60	29	19	1	55	26	18	1
8	39	2	1	0	93	5	2	—
10	9	2	0	0	82	18	0	—
11	0	0	0	0	0	0	0	—

TABLE 7.7 NUMBER OF WOUNDS PER BODY PART, MECHANICAL AND BURN

Figures involved approximately 310 animals but are not additive in terms of animals placed or injured because of multiple type injury or multiple body area involved.

Station	Head and Neck	Thorax	Abdomen Including Rump	Extremities	
				Hind	Forelegs
4	—	1	1	1	1
5	—	—	—	1	—
6	51	69	90	27	25
7	47	79	97	19	22
8	19	35	42	9	9
9	10	5	19	5	5
10	1	1	1	1	—
11	—	—	—	—	—
Percentage body surface involved	20 pct	30 pct	40 pct	5 pct	5 pct

TABLE 7.8 DISTANCE OF ANIMAL DISPLACEMENT BY STATION

Station	Less Than 10 Feet	Distance Displaced, Feet				Total Per Stations Concerned	No. Originally Placed at These Stations
		10 to 49	50 to 99	100 to 149	150 +		
1	—	2	—	2	10	14	20
2	1	—	—	—	16	17	20
3	1	7	8	3	2	21	40
Totals	2	9	8	5	28	52	80

TABLE 7.9 PERCENTAGE OF DIFFERENCE BETWEEN FIELD AND HOSPITAL OBSERVATIONS OF BURN ESTIMATES

Pathologists' estimates used as basis for comparison.

Percent Difference	Number of Animals
+ > 50	1
+ 40 to 50	0
+ 30 to 40	1
+ 20 to 30	5
+ 10 to 20	14
+ 0 to 10	42
+ 0	66
− 0 to 10	50
− 10 to 20	14
− 20 to 30	9
− 30 to 40	4
− 40 to 50	1
− < 50	1
	208

TABLE 7.10 OBSERVABLE FIELD INJURIES VERSUS CAUSE OF DEATH

Stations	Field Observations		Pathologists' Report		
	Mechanical	Burn	Mechanical	Burn	Radiation
1 and 2*	18	1	15	0	1
3	10	10	12	3	1
4 and 5*	0	47	0	17	55
6	29	113	19	7	98
7	47	86	8	1	102
8	51	37	2	1	29
9	25	0	—	—	—
10	0	10	0	0	0
11	0	0	0	0	0

* Stations 1 and 2 and Stations 4 and 5 combined because of similarity of injury induced.

TABLE 7.11 TIME OF DEATH BY STATION

Stations	Animals Placed	Hours		Days							Survivors*
		4	4 to 23	1 to 2	2	3	4	5	6 to 11	12 to 30	
1 and 2	40	37	2	—	—	—	1	—	—	—	—
3	40	33†	2	1	2	2	—	—	—	—	—
4 and 5	79	—	2	2	16	24	23	6	1	—	5
6	145	11	14	—	6	25	32	17	38	—	2
7	145	2	5	—	1	2	6	9	98	13	9
8	110	1	2	—	—	3	—	—	14	17	73
9‡	—	—	—	—	—	—	—	—	—	—	—
10	40	—	—	—	—	—	—	—	—	1	39
11	40	—	—	—	—	—	—	—	—	10	30

* Includes sacrificed.

† Includes 19 animals that were not found but were exposed to lethal radiation fluxes.

‡ Data inadequate.

TABLE 7.12 TIME DEATH VERSUS TYPE OF INJURIES, EXPRESSED IN PERCENT

Type of Injury	Number of Animals Concerned	Time of Death		
		D to D+4	D+5 to D+11	D+12 to D+29
		pct	pct	pct
Radiation	19	48	46	6
Radiation and mechanical	37	17	56	27
Radiation and burn	135	45	50	5
Radiation, mechanical, and burn	101	31	62	7

TABLE 7.13 MEAN DAY OF DEATH OF ANIMALS DYING OF IONIZING RADIATION BY STATION AND EXTENT OF BURNS

Numbers in parentheses are the actual number of animals studied.

Station	Extent of Burn, Percent			
	None	< 20	20 to 40	> 40
4 and 5	(12) 4.6	(22) 3.6	(8) 2.9	(9) 3.2
6	(2) 9.0	(12) 6.1	(11) 5.2	(7) 4.3
7	—	(18) 10.2	(3) 7.0	(5) 6.2
8	(3) 13.0	(5) 21.0	(1) 9.0	—

ANIMAL NO. 516
STATION NO. III (foxhole) and VI

PRESHOT DATA

Time placed: H-5 hrs.

Condition of animal: 50 lbs. Good

Comments: Animal hobbled to prevent escape from foxhole

POSTSHOT DATA

Time observed: H+5 hrs.

Condition of animal: (check appropriate term(s)

Alive ✓ Dead ____

Conscious ✓ Unconscious ____

Vomiting ____ Diarrhea ____

Other: No apparent injury

Met. data:
T-21.0°
H-22%

Significant changes in position:
No displacement or translation

Predicted weapon effects:	Observed weapon effects:
Overpressure 10 psi	Overpressure 9.8 psi (in air)
Thermal Rad 80 Cal/cm²	Thermal Rad 75 (in air) Cal/cm²
Nuclear Rad: γ 6000	Nuclear Rad: γ 6500
η 4000	η 4290

PHOTOS TAKEN	B&W	COLOR	MOVIES
Impact Area	1	1	✓
Sorting	1	2	✓
Resusitation			
Surgery	2	2	✓
Necropsy	2	2	
Other Recovery	✓		

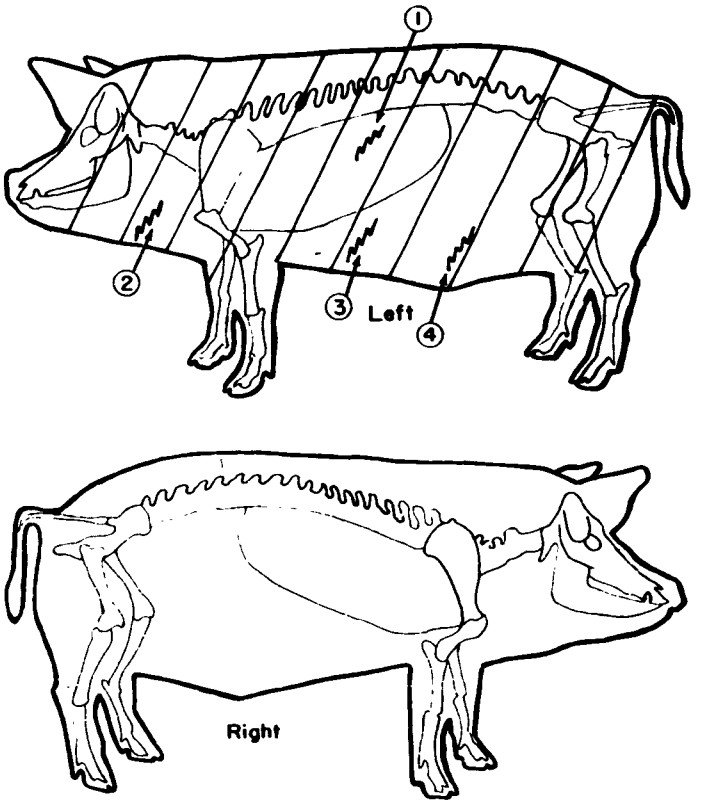
WOUND DESCRIPTION:
(Estimate burn areas, length of laceration, etc.)

Note:

This is a composite record of two animals at two stations.

① BL
② BG
③ BG
④ Small bowel protruding

EXAMINER: SURGEON



KEY

③ Puncture wound (No. of wd.)
~ -Laceration
I-I-I-Abrasion or contusion
////-2nd Degree burn
XXX 3rd Degree burn
O/ Fracture, open
C/ Fracture, closed
BL- Local or superficial bleeding
BG- General or deep bleeding

Figure 7.1 Sample animal field medical tag.

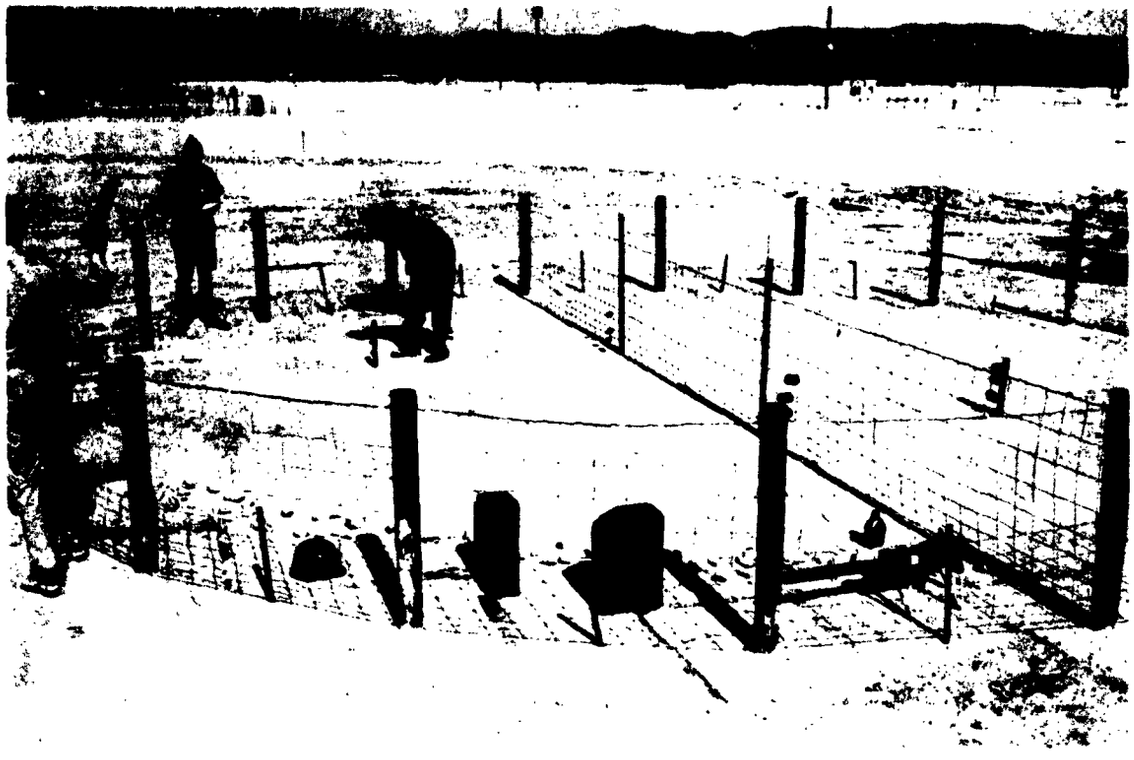


Figure 7.2 Preshot view of Station 5, showing battlefield missile placement.

Figure 7.3 Preshot view of Station 6.

Figure 7.4 Postshot view of Station 5, showing little displacement of battlefield debris.

Figure 7.5 Postshot view of Station 6.

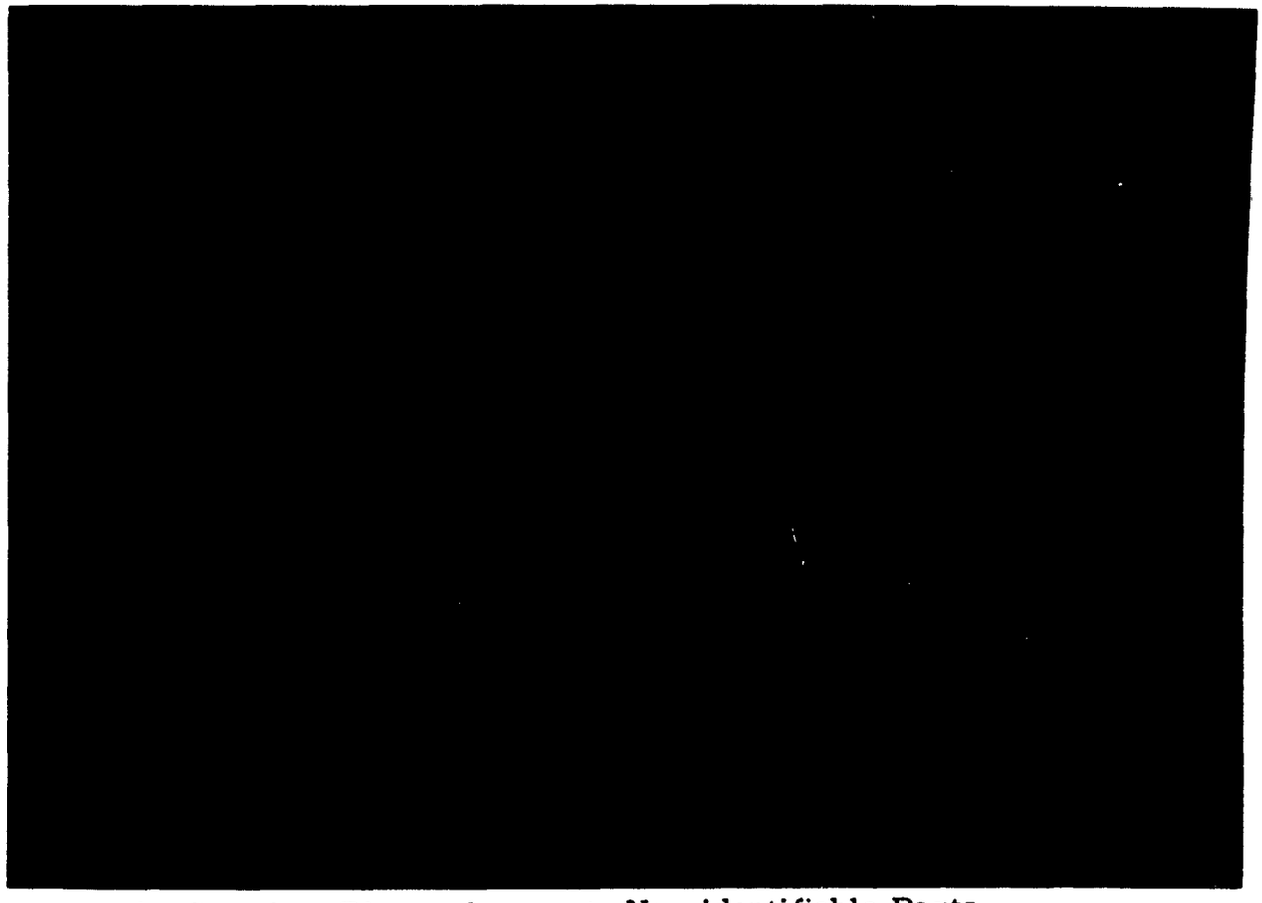


Fig. 7.6 Complete Dismemberment, Non-identifiable Parts

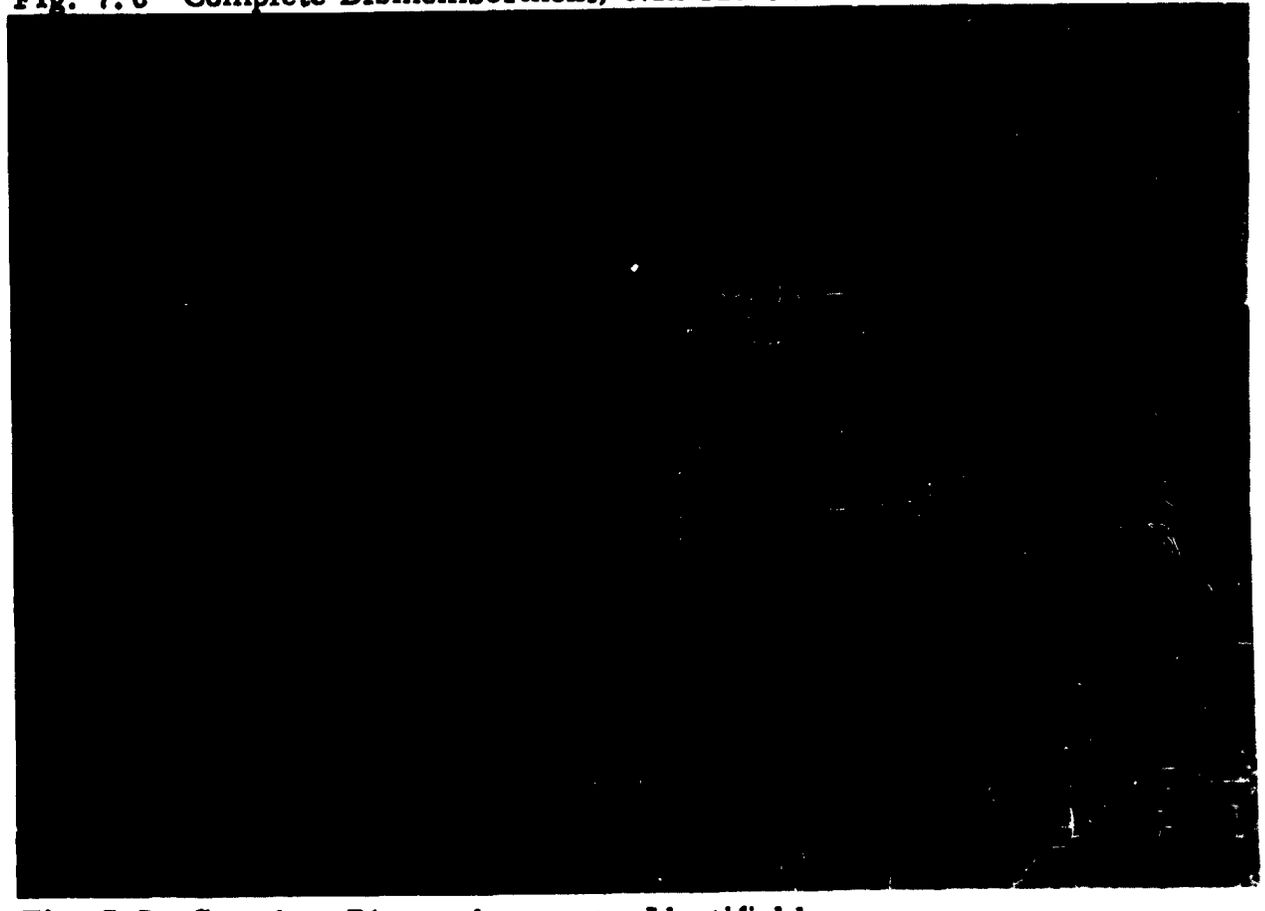


Fig. 7.7 Complete Dismemberment - Identifiable

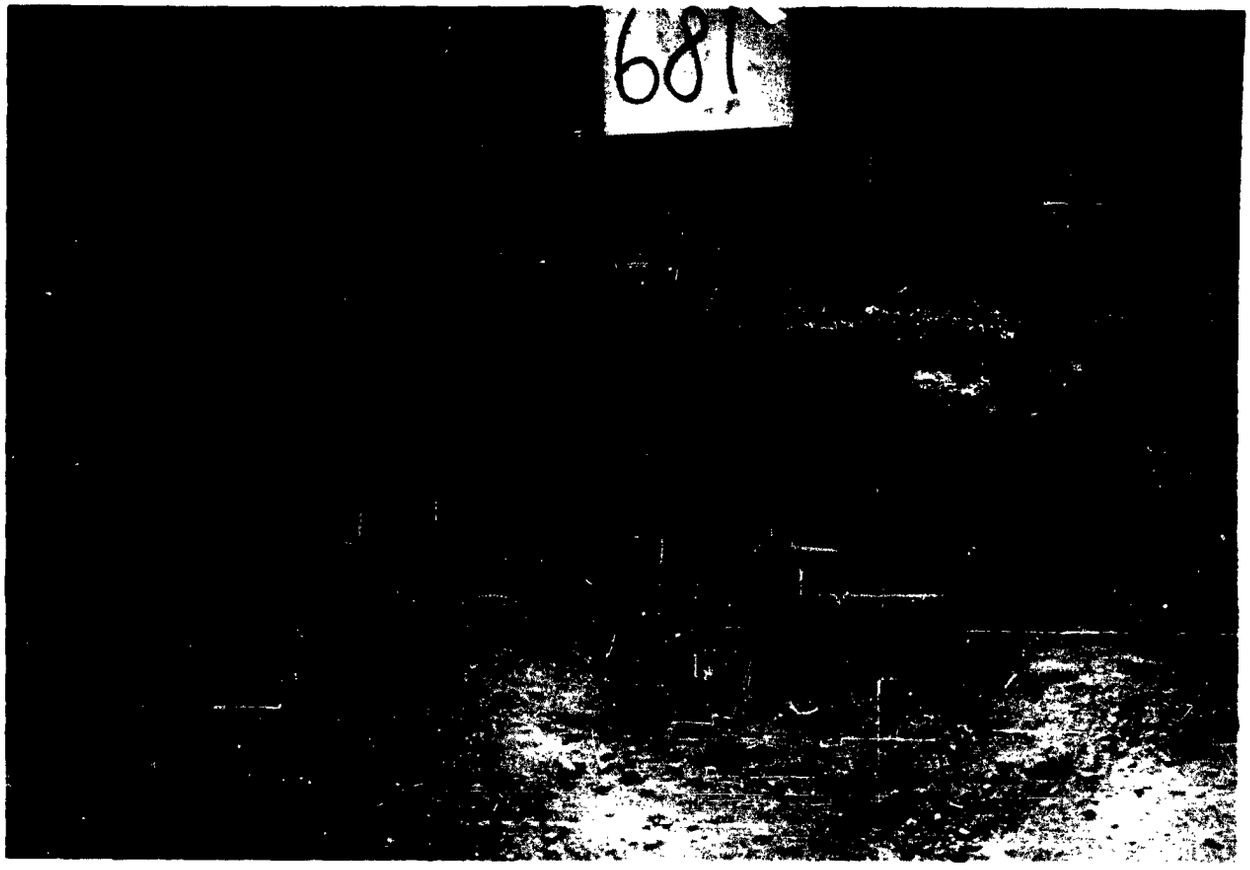


Fig. 7.8 Partial Dismemberment Plus Evisceration

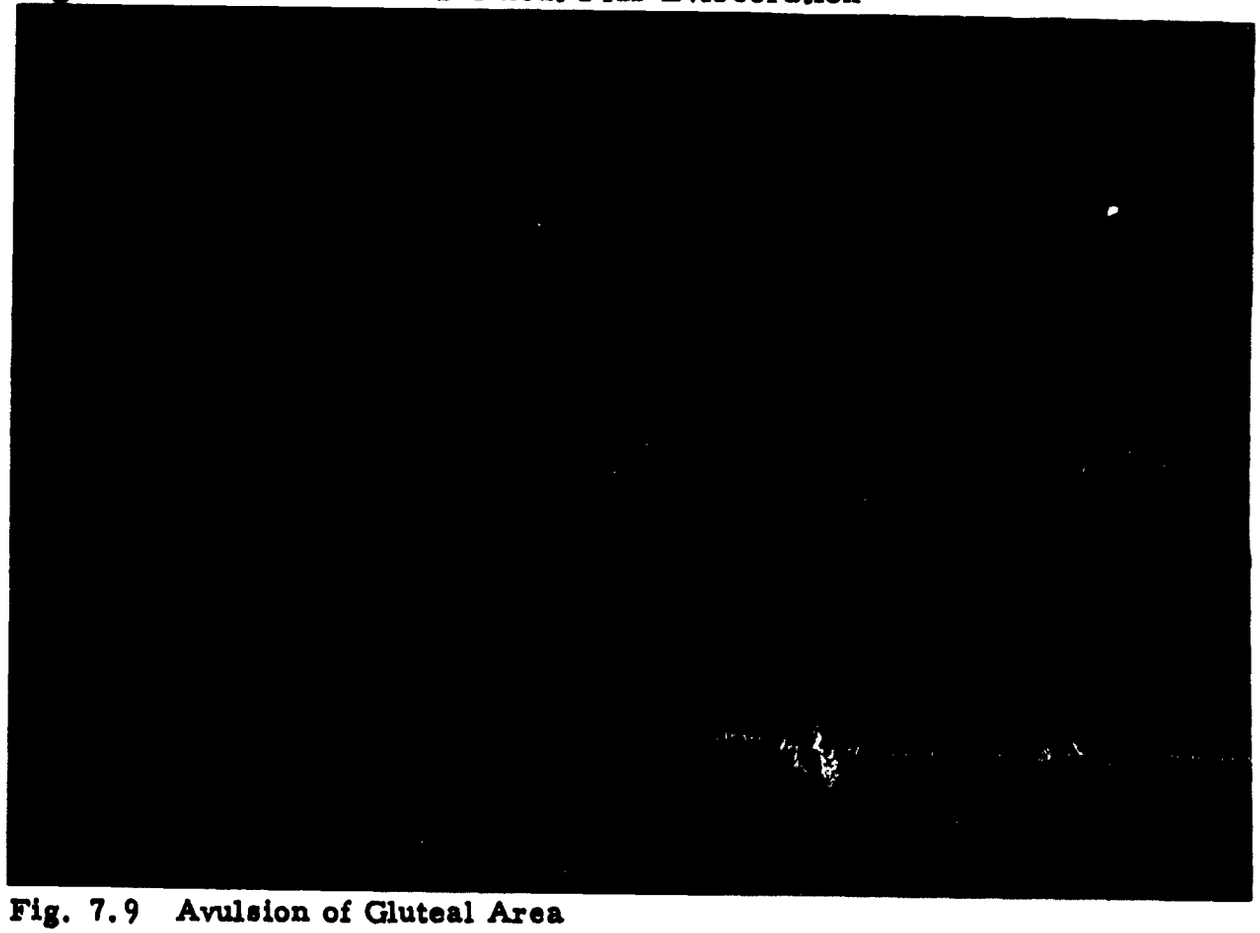


Fig. 7.9 Avulsion of Gluteal Area

Fig. 7.10 Laceration of the Ear

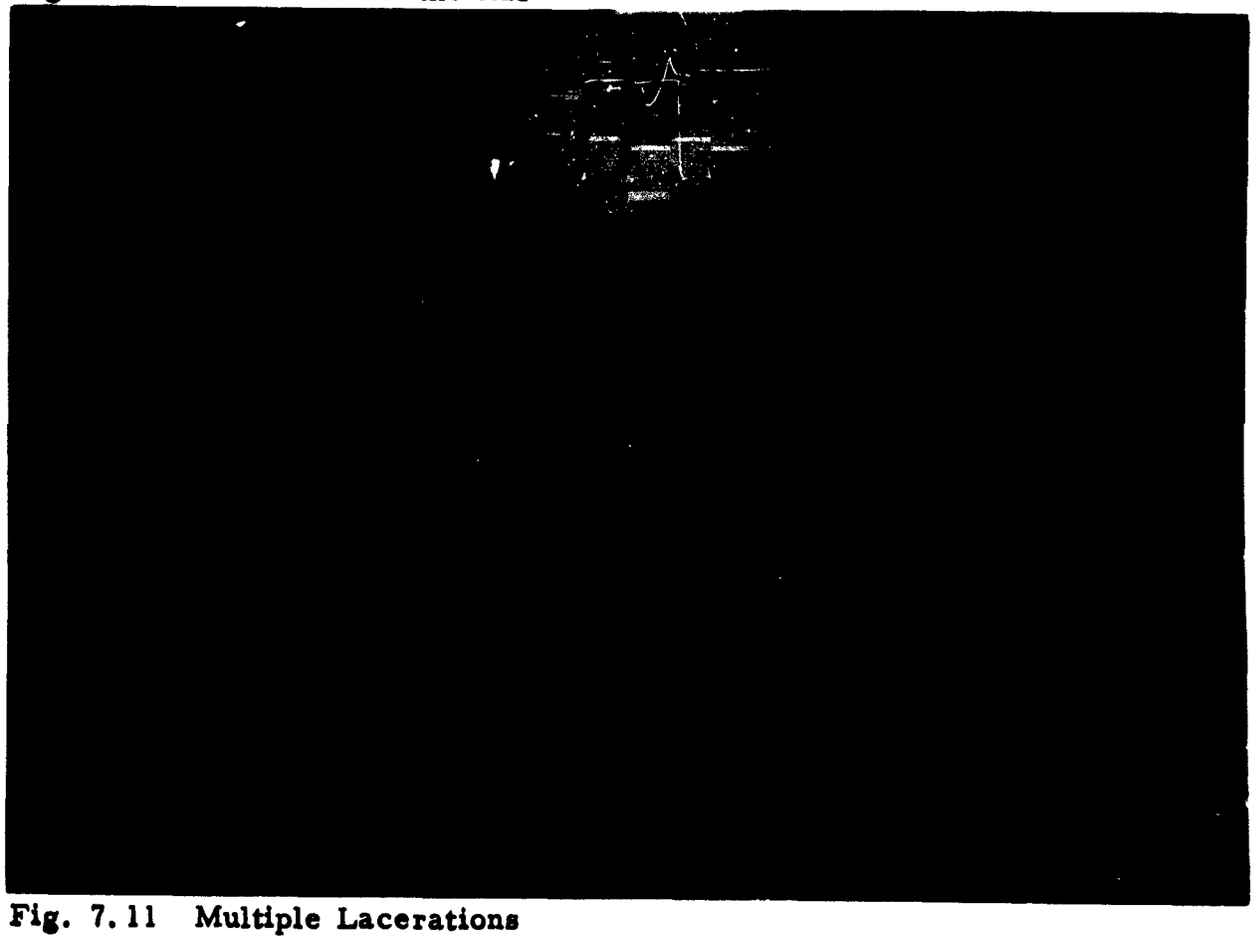


Fig. 7.11 Multiple Lacerations

Fig. 7.12 Penetrating Wound of the Thoracic Cavity

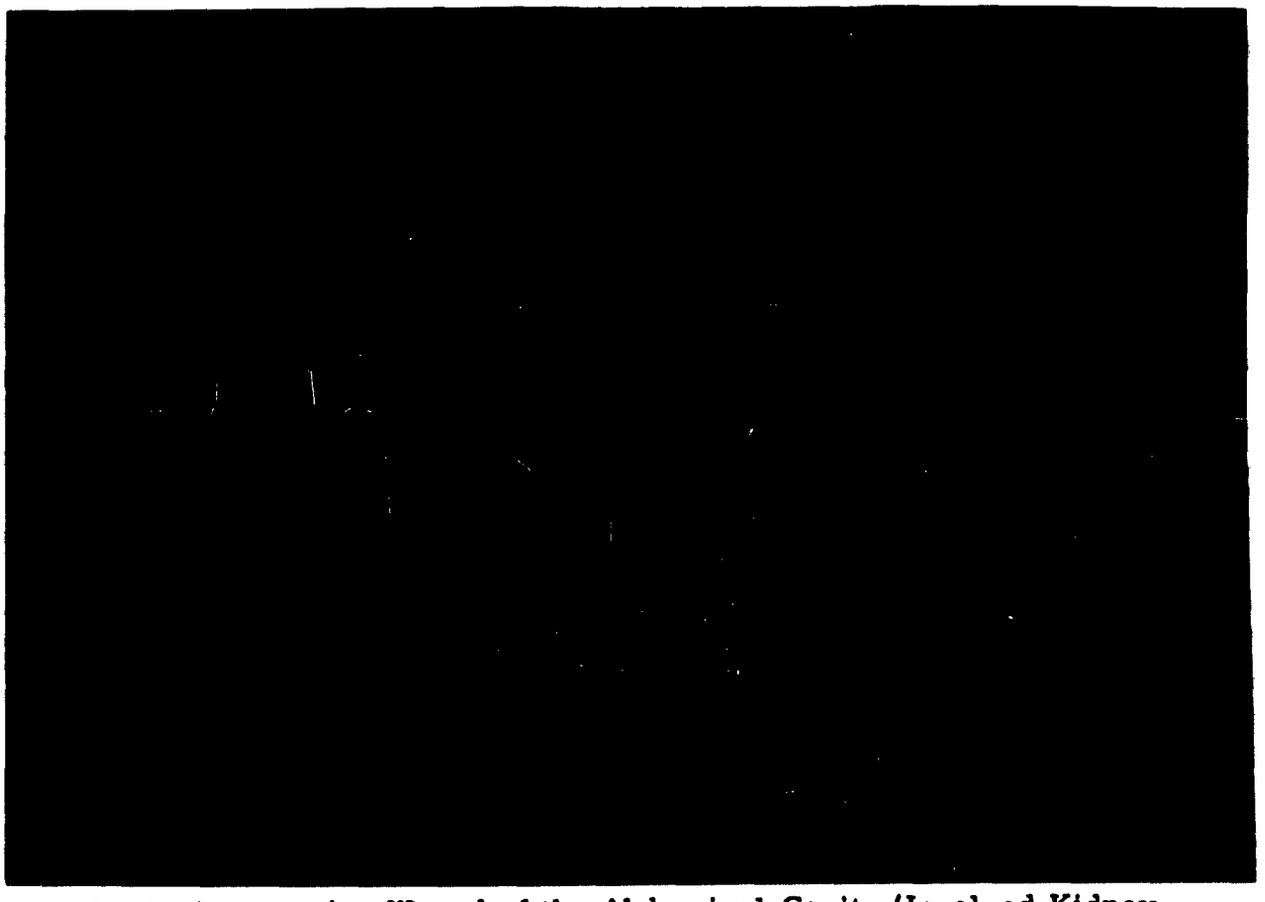


Fig. 7.13 Penetrating Wound of the Abdominal Cavity (Involved Kidney and Bowel)

Fig. 7.14 Evisceration of Intestine following Laceration of Abdominal Wall

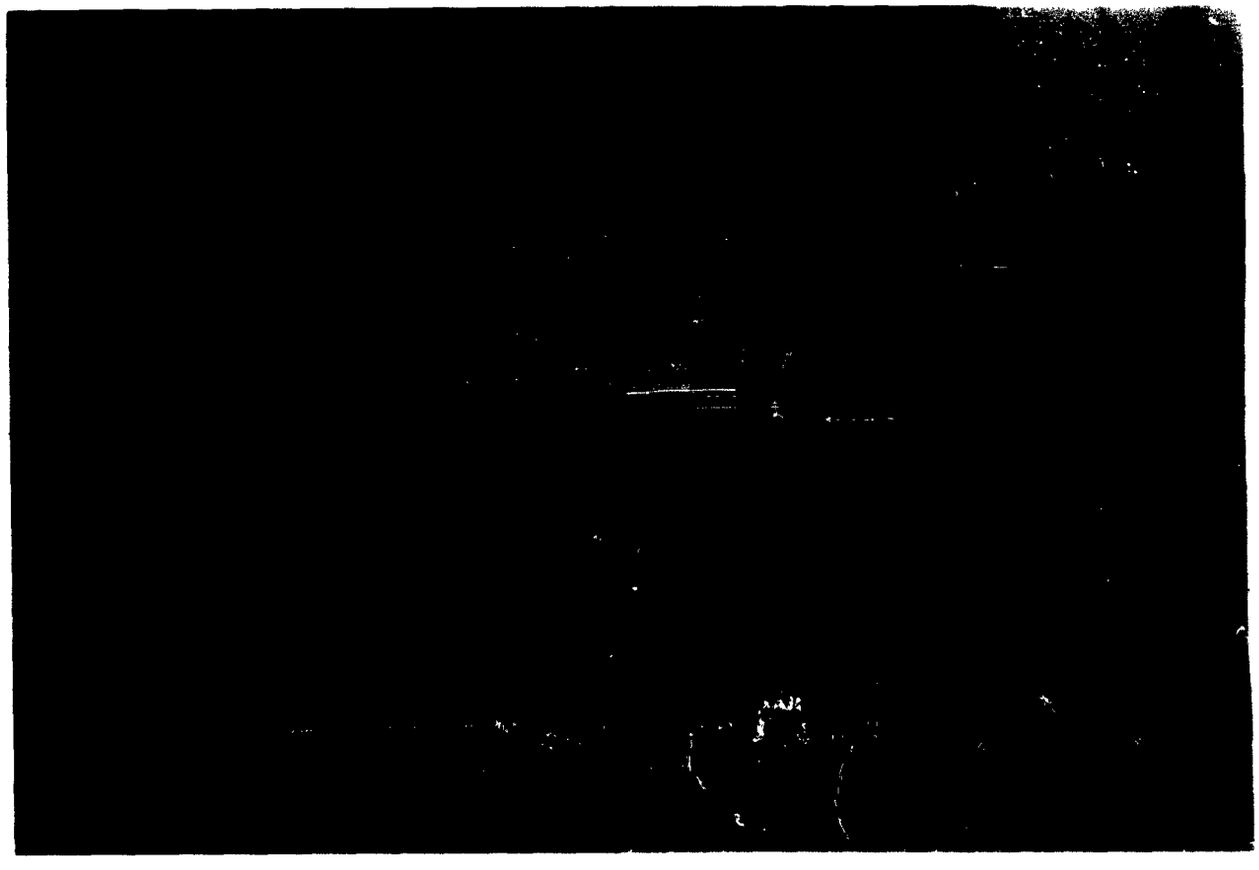


Fig. 7.15 Deep Wound of the Extremity

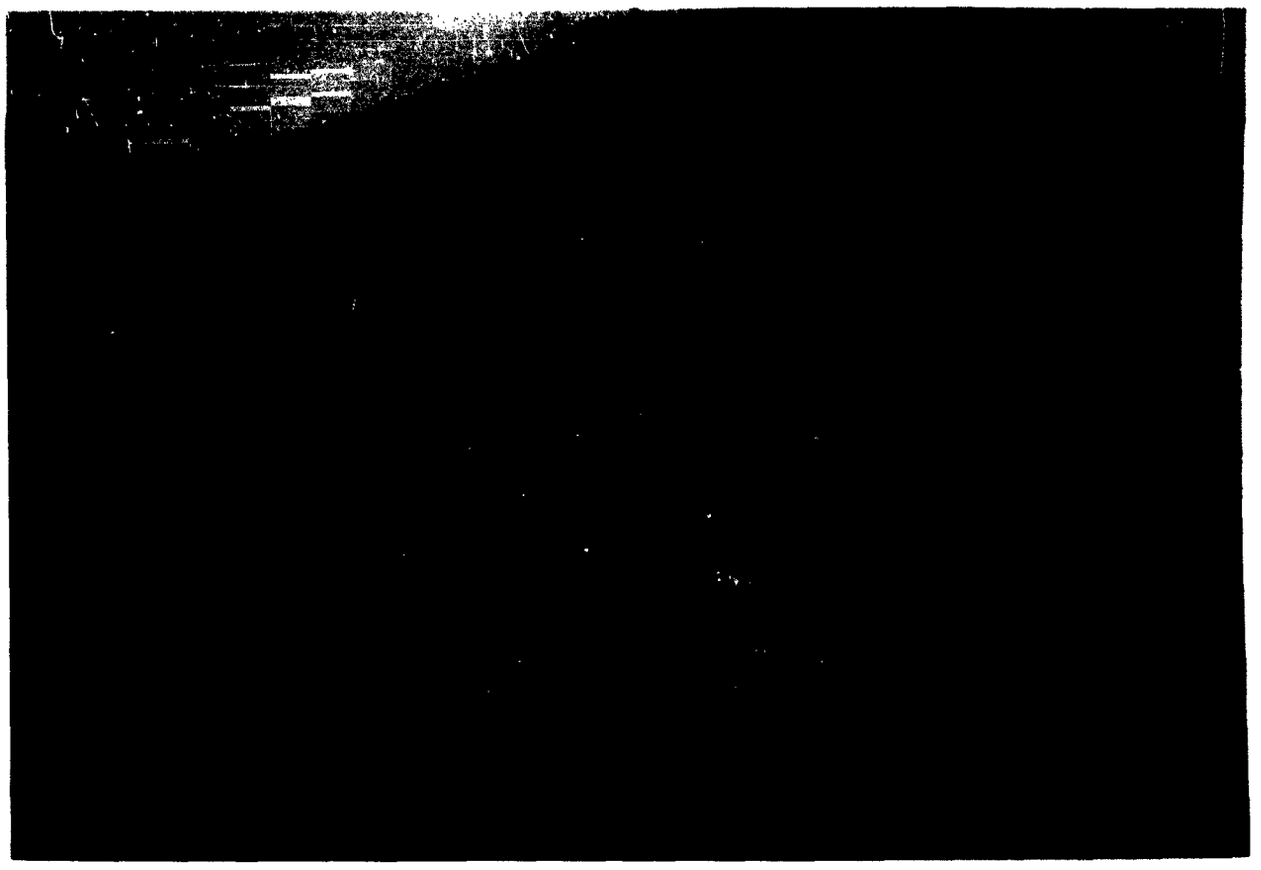


Fig. 7.16 Burn of 20-30% Body Surface

Fig. 7.17 Burn Greater than 40% Body Surface

Fig. 7.18 Burn of the Tongue

Fig. 7.19 Animal Killed within Original Stations from Severe Impact

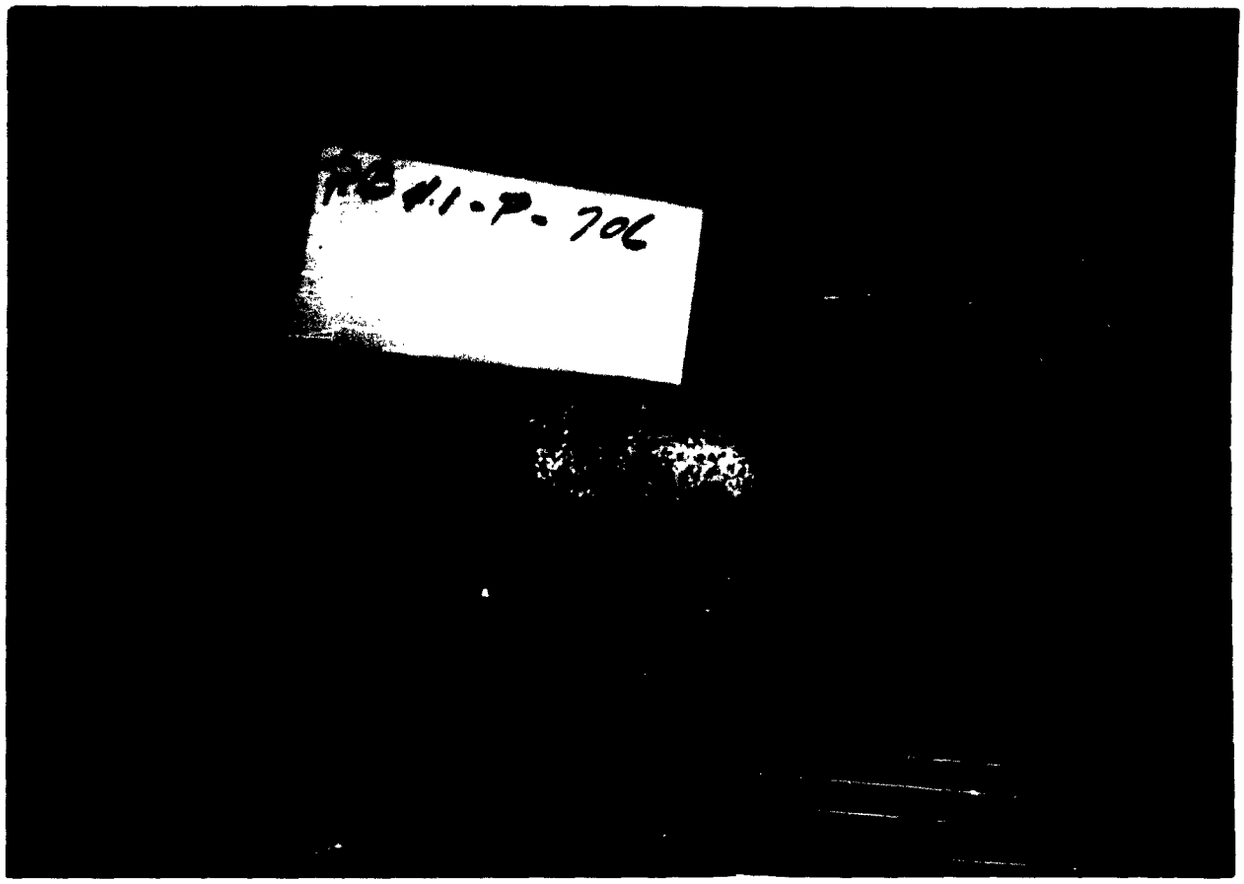


Fig. 7.20 Abdominal Injury due to Flying Can

Fig. 7.21 Glass Missile Path (Thoraco-Abdominal)

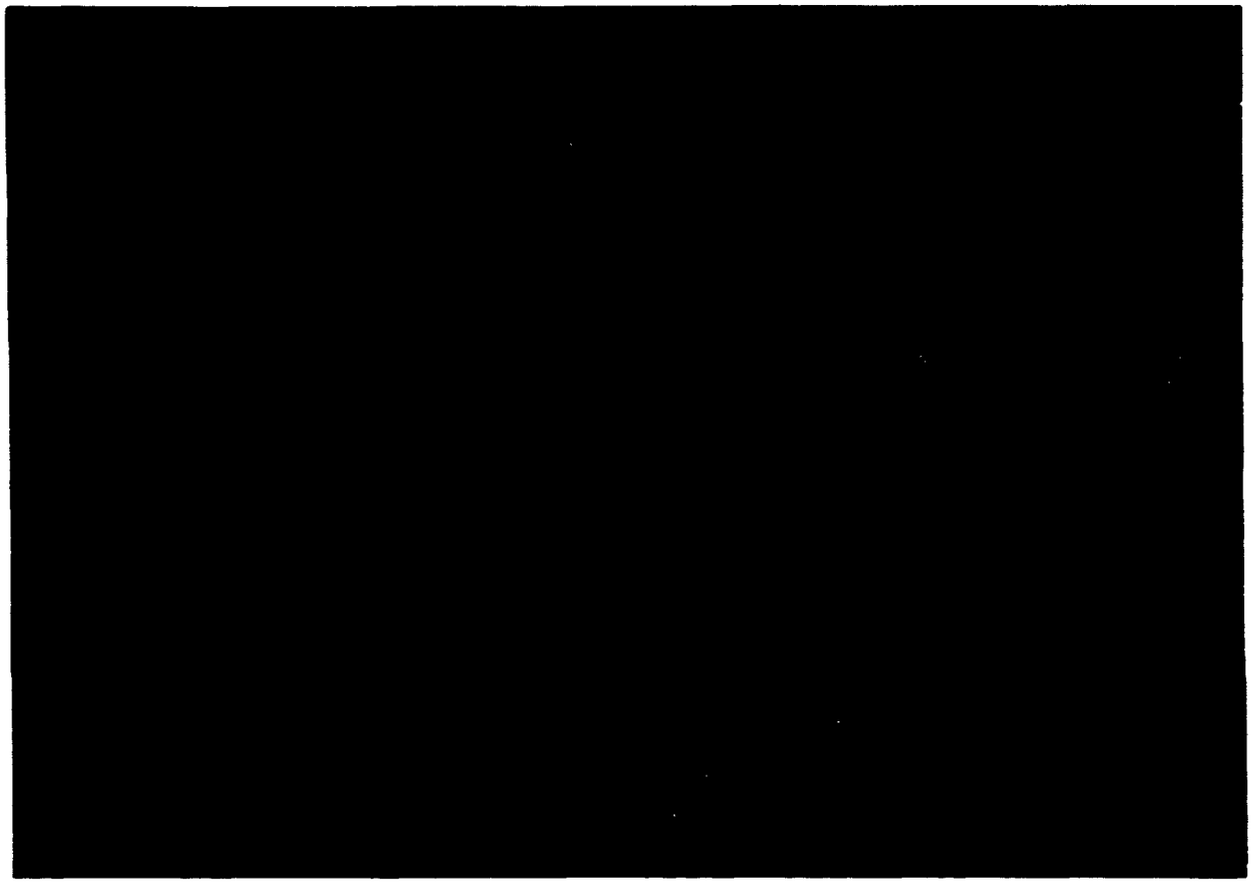


Fig. 7.22 Burned Animal at Point of Recovery (Covered with Dust)

Chapter 8

SURVIVAL STUDIES

8.1 SWINE IN FIELD FORTIFICATIONS NEAR GROUND ZERO, SHOT PRISCILLA

8.1.1 Station Layout. In conjunction with Project 50.6, five swine were placed in machine-gun fortifications near ground zero (Figure 8.1). Figure 8.2 is a perspective drawing of the installation. The retaining walls were constructed of corrugated sheet metal. The animal was restrained in the position shown by means of a rope harness (Figure A.2) made of $\frac{3}{8}$-inch rope and fastened to screw eyes mounted in the supporting members of the structure.

Stations A1, A2, and A4 were oriented so that the front port faced 180 degrees away from ground zero. Stations A3 and A5 had the front port facing 90 degrees away from ground zero, with the side port directly facing ground zero.

The amount of earth shielding to the animal in a line-of-sight direction from the center of the fireball was calculated from the height of burst and distance from ground zero in each case. For Station A1, the shielding was calculated as 9.55 feet; for Stations A2 and A3, 11.2 feet; and for Stations A4 and A5, 14.4 feet. In no case did the roof cover add to the shielding from the direct radiation.

The center of each animal's body was considered to be 16 inches above the floor.

The density of undisturbed soil in this area is given as 90.0 to 93.2 lb/ft^2, with a water content ranging from 10.8 to 11.2 percent. The density of the cover material was estimated to be 80 to 85 lb/ft^3.

8.1.2 Instrumentation. NBS film dosimeters were used at all stations except A5, which was at a distance comparable to Station A4 but with different orientation. Four dosimeters were placed at each location in relation to the head, tail, and midportion of the animal. The dosimeters were secured to supporting structure by wire. All dosimeters and animals were in their original position at the time of recovery. The dosimeters were provided by Project 2.5.

In addition, Project 2.4 provided film-badge dosimetry for gamma detection and chemical dosimeters for total neutron dose.

Blast instrumentation inside the shelters was provided by Project 1.1. The instrumentation measured peak side-on overpressure and pulse duration at three positions: outside the fortification, inside the entrance, and inside the emplacement. The gages inside the emplacement were positioned as shown in Figure 8.3, with each gage 20 inches above floor level.

No thermal measurements were made.

8.1.3 Placement and Recovery. All animals were placed between 2320 and 2345 hours on D−1 day (Table 8.1). Recovery time is also shown in Table 8.1. All dosimeters were recovered simultaneously with the animal, except at Station A3 where they had become buried and were recovered the following day.

8.1.4 Results. All animals were living at recovery time and were delivered to the Project 4.1 hospital site in fair condition. They had been without food and water and immediately ingested of both. There was no evidence of diarrhea or of vomiting at the time of recovery.

Stations A3 and A5 (with the side port toward ground zero) suffered complete destruction of the top cover of the fortification, the emplacement portion being completely exposed.

The results of the blast measurements are given in Table 8.2.

The results of the dosimetry are given in Table 8.3. The survival time of each animal is shown here again for convenience of reference.

Study of the data discloses that the only permanent survivor had been placed in Station A5. The neutron dosimetry is not available. Gamma dosimetry is incomplete and appears inconsistent.

It is probably significant that the only animal which survived permanently (Pig No. 519, Station A5) was also the only animal recovered on D day, 4 hours after the shot. Because of the Rad-Safe restrictions, all other animals remained unrecovered, without food and water, until D+1. They were recovered 32, 32, 28, and 28 hours after the shot at Stations A1, A2, A3, and A4, respectively. Although living at time of recovery, all subsequently died.

The dosages received probably range up to 2,000 rep total dose. In any event, because the animals in Stations A1 through A4 had a radiation injury plus prolonged exposure, it is not possible to rule out additional exposure as being the contributory cause of death. Some of these animals may have survived permanently could they have been recovered sooner.

The fact that one permanent survivor was obtained suggests that minor modifications in the design of the fortification might result in shielding that would be sufficient to ensure permanent survival from a similar experience in the field.

8.2 SWINE EXPOSED TO COMBINED WEAPON EFFECTS, SHOT WILSON

The present discussion concerns the biological response to combined injury observed in 40 swine exposed at four stations during Shot Wilson. Details of the exposure conditions may be found in Appendix A. The survival study on this group of animals is properly separated from Appendix A, because the basic purpose of that experiment was a physical, rather than a biological, study.

The data pertinent to the present discussion is extracted from Table A.2 and is presented in Table 8.4. Figure 8.4 is a semilogarithmic plot of dose versus survival time for each group of animals. Included in Figure 8.4 is a plot of the dose as obtained by the same method versus survival time of the Wilson radiation animals (Chapter 2). This data is included for gross comparison, but it should be clearly understood that the two groups are not directly comparable, because the experimental conditions differed considerably. In particular, the animals exposed during Shot Wilson were protected from thermal effect, as well as from natural missiles, by the aluminum liner in which they were placed and, hence, received purely a radiation insult, without incurring burn or trauma. On the other hand, the blast-missile animals were deliberately exposed to all weapon effects, incurring severe burns—at least superficial wounds—and supralethal doses of irradiation.

It is reasonable to conclude that the survival time following a lethal dose of radiation delivered to a biological specimen, in the presence of both serious burn and trauma,

would be significantly decreased over a pure radiation injury. Because it is not possible to determine the quantitative effect of each component in the present experiment, no effort has been made to draw a smooth curve through the plotted points.

If it can be assumed, for a pure radiation study of survival time of a biological specimen, that the experimental points in a significant number of animals should fall on a smooth curve, then the present results suggest one of two conclusions: (1) The first two points, representing the mean survival time at Stations 12 and 13, may represent the greatest deviation from a smooth curve that would result from a pure radiation injury. This is a reasonable interpretation, because the greatest burn and trauma were incurred at these stations. Thus, if these two points, at the same dose level, lay further to the right (longer survival without burn and trauma), the data would then fit a smooth curve. (2) On the other hand, there actually was no statistically significant difference between the degree of burn and trauma among the four stations. Hence, the previous conclusion is hardly justified. If the mean survival time at Station 14 had been 52 hours instead of 68, the data would have fit a smooth curve. Generally speaking, the results are probably within normal limits of variation of a biological experiment.

The most reasonable interpretation of the data is to consider it as representing simply the survival time of a large biological specimen exposed to the combined weapon effects.

8.3 SWINE IN TANK NEAR GROUND ZERO, SHOT WILSON

Four pigs were used during Shot Wilson to determine the tissue dose of irradiation received by crew members within a tank. The animals had had a chemical dosimeter surgically placed along the lesser curvature of the stomach several days prior to the shot. The plan was to sacrifice the animals immediately after recovery. No survivors, therefore, were anticipated.

The four pigs used in the experiment received 16 mg of atropine in 2 cc of aqueous solution administered subcutaneously at H−7 hours. The animals were anesthetized at H−6.5 hours with Dial and Urethane anesthetic administered intraperitoneally (Table 8.5). The solution had a concentration of 100 mg/cm^3.

Each animal was loaded onto the truck immediately after administration of the anesthetic. The truck left immediately for the tank area. The anesthetic attains maximum effect in 30 minutes to 1 hour after intraperitoneal administration. As soon as maximum effect was noted, each animal was placed in a restraining device, while enroute to the tank area.

The restraining device consisted of a V-shaped trough 3 feet long, constructed of 1- by 8-inch lumber, and open at one end. The posterior end of the pig was placed at the closed end of the trough, with the dorsal surface of the pig resting in the trough (leaving a portion of the sides and the ventral surface exposed). All pigs were so restrained while enroute to the tank area and were subsequently placed at H−5 hours.

The pigs placed in the driver and gunner positions were in an upright position to resemble the position of a crew member; those placed in the tank-commander and assistant-gunner positions were placed on their right side. All pigs were secured in position by ropes from the restraining devices to various structures within the tank. Placement was completed by H−4 hours. The tank was located with the right side situated nearest ground zero.

It is reasonable to assume that all four pigs were alive until the time of the shot, because other animals retrieved after cancellation of a shot were alive. The previously

placed animals were of comparable weight range and health and were placed under identical conditions at approximately the same times. These animals were retrieved at what would have been H+1 hour (had the shot been fired) and were found to be in good condition and completely anesthetized.

Following the actual shot, recovery of the animals was not accomplished until H+12 hours, because of Rad-Safe restrictions. Upon recovery, there was no evidence of struggling on the part of the animals within the tank from their original position. All animals had evidently been dead for several hours, judging from the post mortem changes seen. Pathology findings were essentially negative when the dosimeters were recovered at autopsy.

The results obtained from the midline dosimeters are presented in Table 8.6. Because of the extremely high doses, there is no possibility that a human tank crew could survive a similar experience.

TABLE 8.1 BIOLOGICAL RESPONSE OF SWINE IN MACHINE-GUN FORTIFICATIONS NEAR GROUND ZERO

Station Number	Animal Number	Weight	Time of Recovery		Radiation Level	Survival Time	Clinical and Pathological Findings	Cause of Death
			Day	Hour				
		lb			r/hr	hr		
A1	503	30	D+1	1500	2.0	97	Right-sided burns of dorsal and ventral portions with normal band slightly above middle; total: 30-percent burns.	1, radiation 2, burns
A2	520	50	D+1	1450	1.0	109	Left-sided 80-percent burn, 2 and 3 degrees.	1, radiation 2, pneumonitis
A3	473	30	D+1	1030	*	173	Bilateral burns of dorsum of animal, slightly greater on left (i.e., extending down about 4 inches in profile on left and 2 inches on right); peri-aortic hemorrhages; auricular, mediastinal, mesenteric and cervical node hemorrhages; hemorrhagic mucosa, gastrointestinal tract (castrated male).	1, radiation 2, burns
A4	474	48	D+1	1045	1.0	235	100-percent right-sided burn.	1, radiation 2, burns + pneumonitis
A5	519	*	D	1030	2.0	—	Permanent survivor. WBC on D+16 was 19,100 (normal for pig).	—

* Unknown.

TABLE 8.2 BLAST MEASUREMENTS IN MACHINE-GUN FORTIFICATIONS, SHOT PRISCILLA

Station Number	Entrance		Emplacement		Outside	
	P_s	Duration	P_s	Duration	P_s	Duration
	psi	msec	psi	msec	psi	msec
A1	25.2	*	17.8	209	52	444
A2	*	*	13.9	*	25.4	447
A3	14.17	552	19.2	*	25.4	447
A4	14.67	530	12.9	502	11.2	629
A5	14.4	*	15.2	611	11.2	629

* No record.

TABLE 8.3 DOSIMETRY WITHIN MACHINE-GUN FORTIFICATIONS, SHOT PRISCILLA

Station Number	Gamma Dose		Survival Time
	Project 2.5	Project 2.4	
	r	r	hr
A1	1,000*	140†	97
A2	1,000*	1,100†	109
A3	600*	‡	173
A4	360*	210†	235
	360	—	—
	230	—	—
	225	—	—
A5	—	720†	Permanent

* Approximation; experimental film; value probably high.
† Film badge in pig compartment, R1 in Figure 8.3.
‡ Not recovered.

TABLE 8.4 SURVIVAL TIME VERSUS DOSE, SHOT WILSON, MISSILE ANIMALS

Station Number	Number of Animals	Mean Percent Total Body Burn	Mean Survival Time	Gamma Dose*	Neutron Dose†	Total Dose
			hr	rep	rep	rep
12	10	22	30	5,290	8,000	13,290
13	10	26	37	4,180	6,130	10,310
14	10	23	68	3,060	4,180	7,240
15	10	20	89	1,245	1,390	2,635

* Oak Ridge National Laboratory goal post line, chemical dosimetry.
† Oak Ridge National Laboratory, Hurst fission foil method.

TABLE 8.5 AMOUNTS OF ANESTHETIC ADMINISTERED TO PIGS IN TANK, SHOT WILSON

Pig Number	Position in Tank	Weight	Dial-Urethane Dosage
		kg	cc
676	Driver	32.76	19.6
652	Gunner	33.18	19.9
651	Tank commander	31.36	18.8
920	Assistant gunner	32.72	19.6

TABLE 8.6 MIDLINE GAMMA DOSIMETRY IN SWINE IN TANK NEAR GROUND ZERO

Position	Pig Number	Gamma
		r
Driver	676	17,750
Gunner	652	18,100
Tank Commander	651	23,000
Assistant Gunner	920	18,500

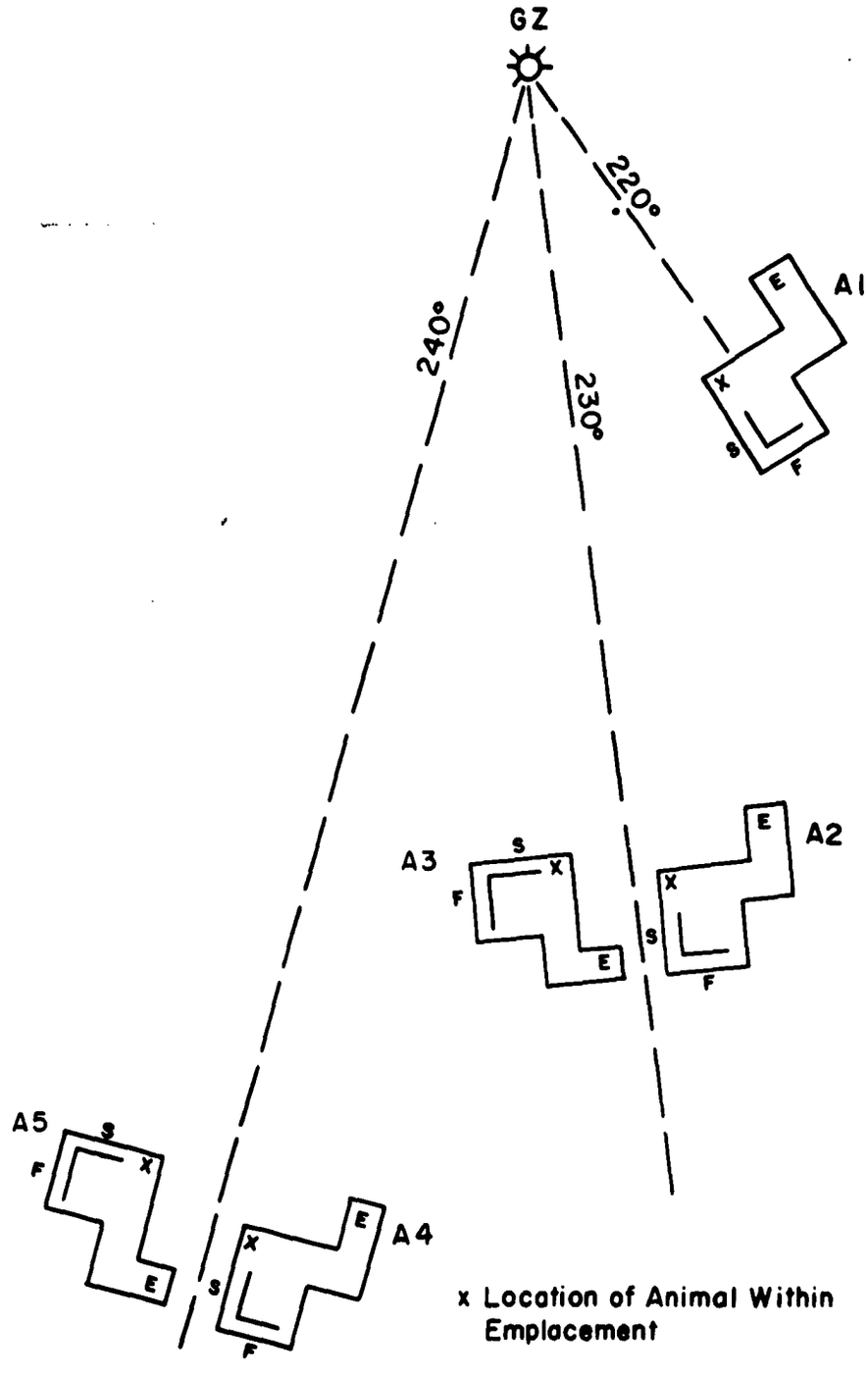


Figure 8.1 Location and orientation of machine-gun fortifications, Shot Priscilla.

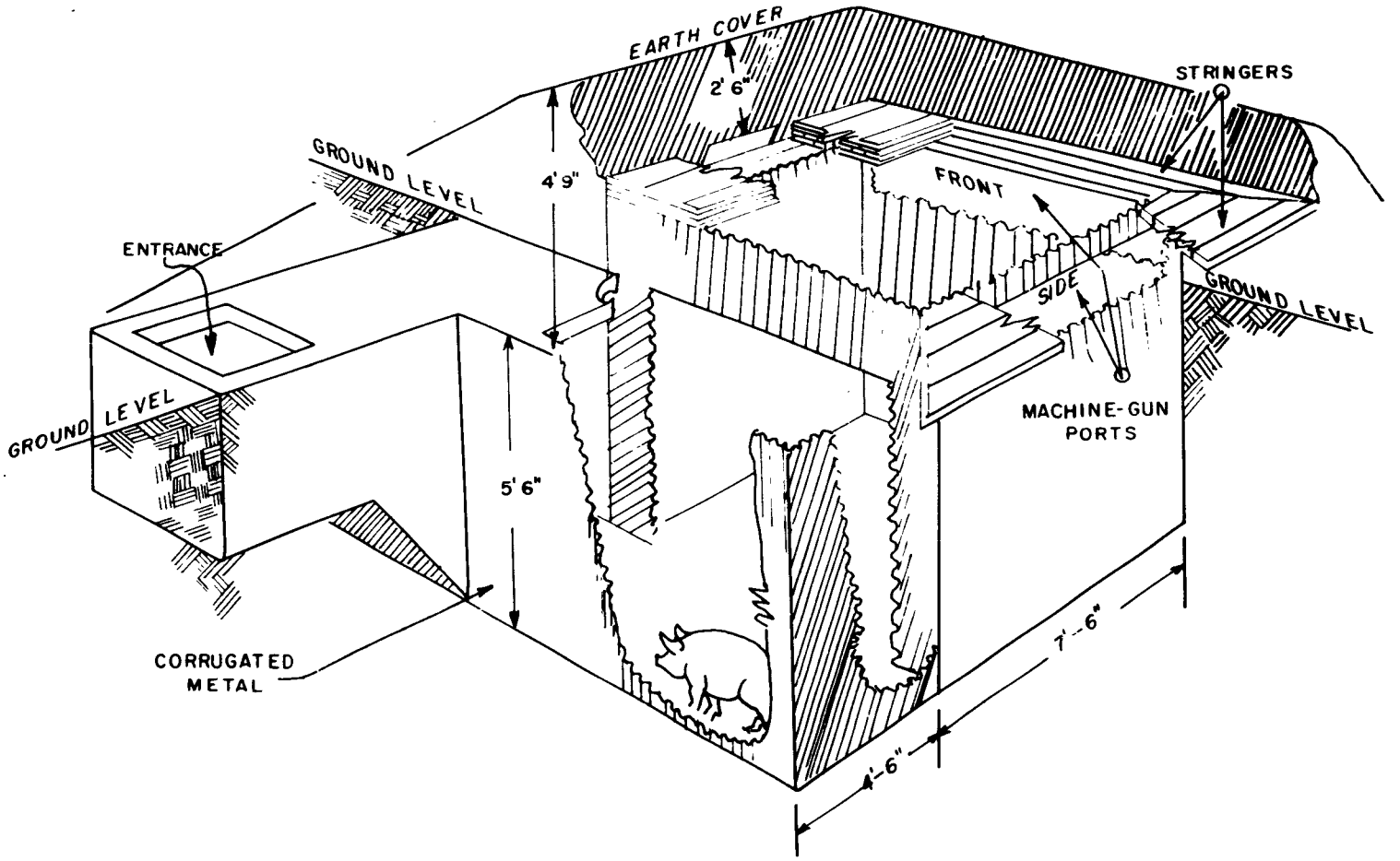


Figure 8.2 Machine-gun fortification.

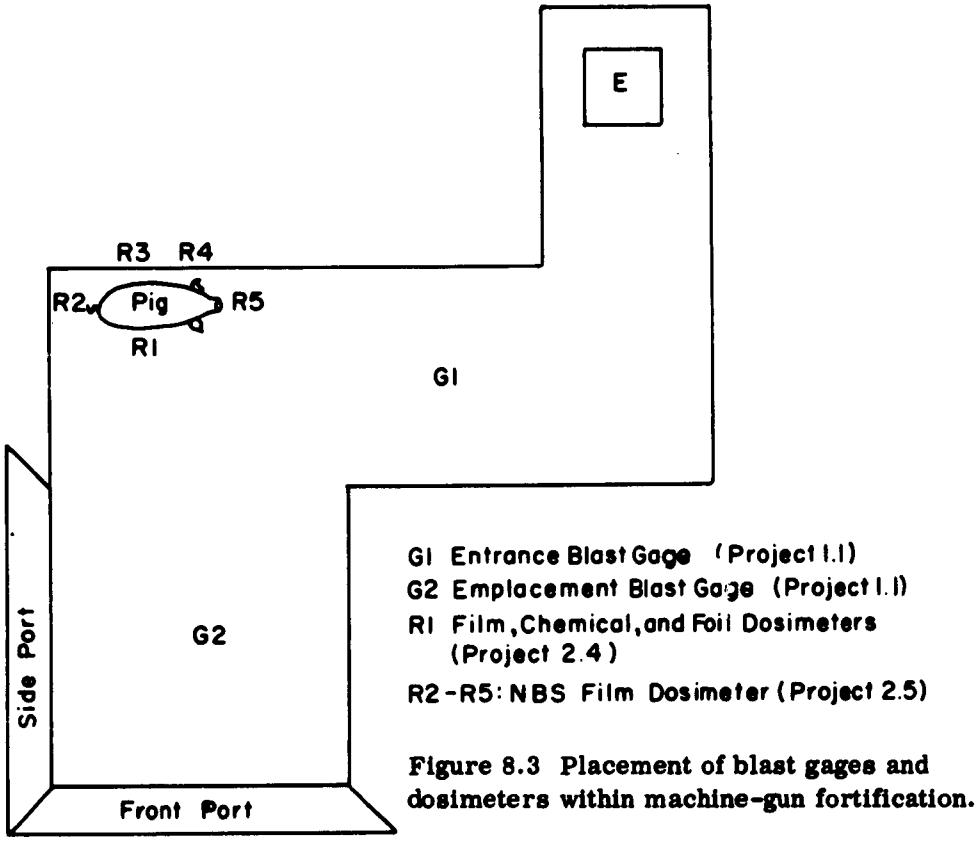


Figure 8.3 Placement of blast gages and dosimeters within machine-gun fortification.

Figure 8.3 Placement of blast gages and dosimeters within machine-gun fortification.

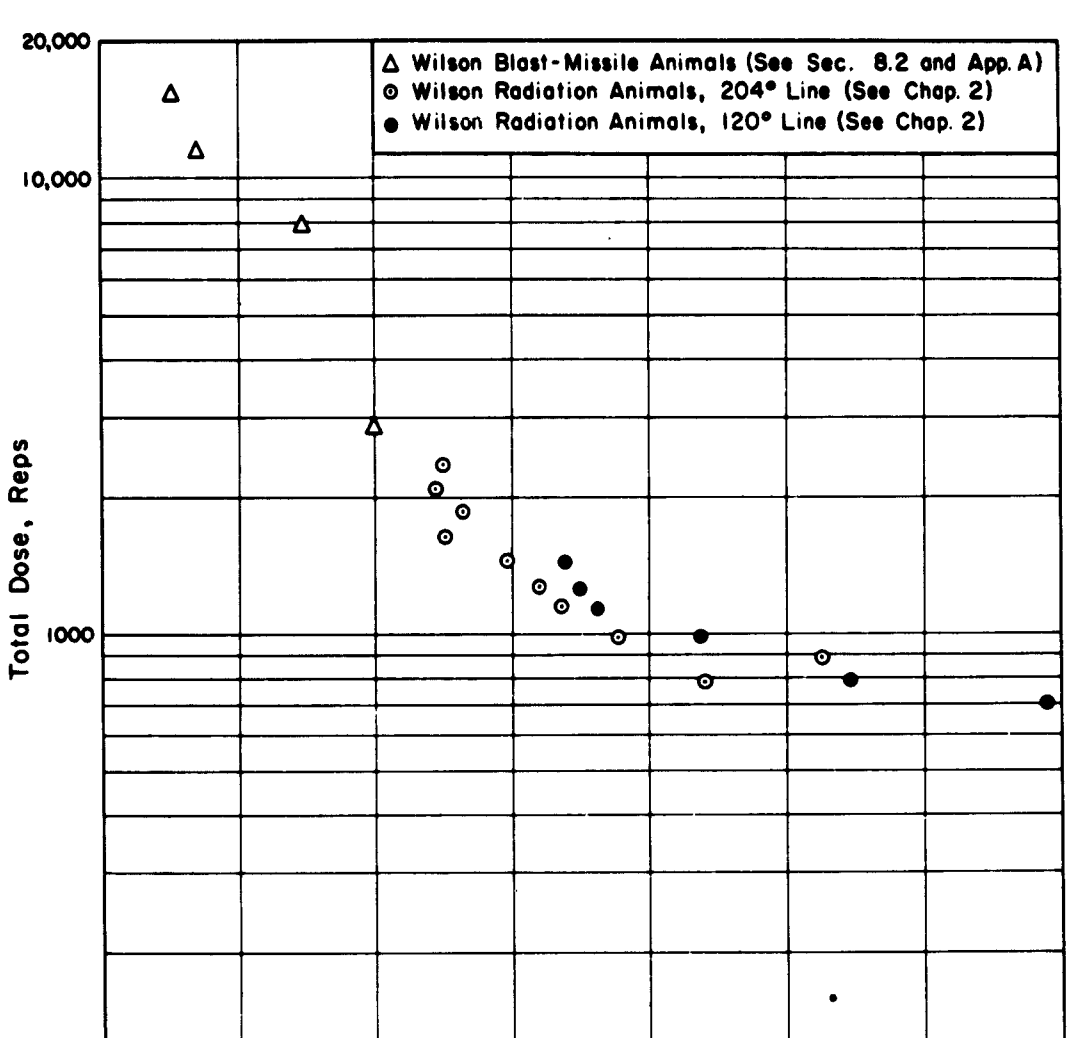


Figure 8.4 Total dose versus survival time, Shot Wilson.

Chapter 9

MISSILE VELOCITIES AND SWINE PENETRATION

9.1 BACKGROUND

The extensive experience of the Lovelace Foundation for Medical Research (References 29, 30, and 31) establishing penetration criteria of glass fragments for the dog was reviewed. It was desired to obtain some correlation with swine. Before this could be done in the field, it was necessary to determine the velocities to be expected of glass missiles and their effect on swine in various attitudes to the missile flight. Extensive background data was accumulated by use of the shock tube at the Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland. The field experiment was based on this data (Reference 32).

Shock-tube experiments proved that glass mounted in a frame of any type that will maintain the periphery of the glass plane in an unmovable state will result invariably in breakage of the pane at peak side-on pressure as low as 1.0 psi.

The size of the fragments resulting from breakage is a function of the peak side-on overpressure, the pane dimensions, and the thickness of the glass. The higher the peak side-on overpressure, the smaller the resulting fragments. Within the ranges of peak overpressure of 8.0 to 4.0 psi the sizes of the resulting fragments were adequate for the purpose of producing wounds. Larger panes of glass appeared to produce larger fragments.

The greater the thickness of the glass used as a missile origin, the larger were the resulting fragments. Thus, plate glass and double-strength and single-strength window glass gave fragments of decreasing size in this order. Double-strength glass, however, generally produced fragments with sharper edges and because it has a significantly larger ratio of area to mass than has plate glass, double-strength glass attained higher velocities and, in the few animal experiments conducted, appeared to produce more significant wounds.

The velocities acquired by the glass fragments in the shock tube were inadequate for production of a significant number of penetrating wounds; however, this was due largely to the short pulse duration. The over tenfold increase in duration of the field pulse from a nuclear device, compared to to that obtained in the shock tube, would impart sufficient additional velocity to the glass missiles so that a definite, though small, probability for penetration would exist for a large number of fragments. The design of the glass array (Appendix B), in such a manner as to provide an extremely large number of fragments, all originating at an optimum distance from a biological target, would overcome the low probability of penetration and provide the requisite number of penetrating wounds.

9.2 PROCEDURE

In conjunction with CETG Projects 33.2 and 33.4, swine were placed in the lower section of a trap and exposed to glass missiles. Four animals were utilized at four exposure stations.

The combined pig-missile trap installation was placed at the south extremity of the exposure line at each station (Figure A.1). The lower trap, at ground level and measuring $42\frac{3}{4}$ by 13 by 27 inches, contained the animal. The upper trap, measuring $42\frac{3}{4}$ by 13 by $15\frac{1}{8}$ inches, contained 12 inches of commercial Styrofoam 22, in which the missiles were trapped and subsequently analyzed for mass, velocity, and spatial distribution. The lower margin of the functional Styrofoam in the upper trap was $28\frac{7}{8}$ inches above the earth. The Styrofoam was inset 1 inch from the front face of the trap, and the area of functional Styrofoam measured $11\frac{3}{8}$ inches in height and $35\frac{1}{4}$ inches in width.

A pig was placed in each lower trap, with the long axis of the body at right angles to the blast line. The animal was restrained in optimum orientation by means of a rope harness (Figure A.2). A single 1-inch layer of Styrofoam was placed behind the animal within the pig box. It measured 24 by 36 inches, and its lower margin was $1\frac{1}{2}$ inches above the earth.

Directly in front of the animal-trap installation was placed an array of ordinary double-strength glass window panes. Each pane measured 16 by 20 by 0.125 inches. The overall array consisted of twelve panes of glass and measured 60 by 64 inches, the lower margin being flush with the earth. The distance from glass to trap at each station was 12.8 feet. Details of this installation may be found in the reports of the CETG Projects 33.2 and 33.4 (References 32 and 33).

Thermal protection was provided by two layers of aluminum foil, with 1-inch separation, located in front of the traps.

Following the shot, the animals were recovered and wound tracts, where found, were explored for depth of penetration. The missile, if present within the wound, was preserved for future reference. Documentary photographs were obtained prior to and after the shot, as well as at autopsy.

9.3 RESULTS

9.3.1 Missile Analysis. The results are presented in Table 9.1. The missile analysis was carried out by the Lovelace Foundation (References 33 and 34).

9.3.2 Wound Analysis. All observed wounds were superficial, extending to a depth of less than 1 cm. No penetrating wounds were found. Three of the four animals died ultimately of radiation, showing at autopsy the usual findings of radiation death. These consisted of pulmonary edema and focal petechial hemorrhages of the lungs, lymph nodes, gastrointestinal tract, and the like. The thermal shielding was completely effective, and no thermal burns were observed. There was some evidence of rope burns due to the harness.

The results, including survival times, are presented in Table 9.2.

9.4 DISCUSSION

The absence of severe wounds, as well as of penetrating wounds, is believed to be the result of the statistically small sample exposed. Gross inspection of the Styrofoam indicates the presence of numerous fragments which, had they struck the animal, should have produced significant wounds.

9.5 CONCLUSION

The failure to obtain significant wounds is believed to be due to the small number of animals exposed.

TABLE 9.1 MISSILE ANALYSIS, TRAP STATIONS, SHOT PRISCILLA

Distance from glass to trap was 12.8 feet at all stations.

	Trap Number			
	8 P 10b	6 P 10b	5 P 9b	4 P 9b
Maximum peak overpressure, psi	8.2	6.1	4.9	3.7*
Dynamic pressure, psi	1.9	0.76	0.48	0.26
Pulse duration, msec	840	930	980	1,040
Total number of missiles	204	32	52	62
Geometric mean velocity, ft/sec	160	110	119	110
Geometric mean mass, grams	0.30	1.01	0.90	1.24
Standard error of estimate, log units	0.078	0.084	0.088	0.093
Number of animal wounds	9	3	8	4
Number of penetrating wounds	0	0	0	0

* Extrapolated.

TABLE 9.2 WOUND ANALYSIS

Trap Number	Animal Number	Peak Side-on Overpressure	Animal Weight	Radiation*		Survival Time	Number of Wounds, All Superficial
				Gamma	Neutron		
		psi	lb	r	rep	hr	
8 P 10b	517	9.2	39	1,500	770	110	9
6 P 10b	507	6.1	53	435	180	181	3
5 P 9b	514	4.9	49	197	19.4	313	8
4 P 9b	504	3.7	50	65	—	Permanent	4

* Program 39.

Chapter 10

BIOLOGICAL EFFECTS NEAR GROUND ZERO

10.1 OBJECTIVES

Because of a paucity of information relative to translation of large biological specimens, as well as possible trauma resulting from secondary missiles, both within and immediately outside of the precursor, it was decided to study such effects during the biomedical experimentation of Operation Plumbbob. At the same time, it was felt that further knowledge could be gained concerning blast, radiation, and thermal effects upon large biological specimens exposed at close ranges to a nuclear detonation.

10.2 BACKGROUND

Previous studies of this kind were few, and the results are difficult to correlate. A theoretical development by a British source (Reference 35) with respect to the standard man gives some concept of the velocities and distances of translation to be expected. The drag coefficients for man and for large biological specimens are not well known and are not considered reliable.

Translation of swine exposed to blast in a shock tube was studied by the present group in the pretest phase of the project. With a relatively short pulse at peak side-on overpressures from 5.0 to 7.9 psi, appreciable velocities and translation were obtained.

Previous efforts to photograph anthropometric dummies have given limited results because of the problem in the field of dust obscuration. Further studies of this type were done in the present series by the CETG, Project 33.3 (Reference 36), with satisfactory results by the use of a stabilized area.

10.3 EXPOSURE STATION DESIGN

Five exposure stations were used in this study. Stations 1 and 2 were identical in design. They were rectangular, measuring 10 by 20 feet, with the long dimension parallel to the blast line. The hog wire fence was 42 inches high. The pens were subdivided internally (Figures 10.1 and 10.3). Each of the two segments contained ten animals. No artificial missiles were employed at these two stations.

Stations 3, 4, and 5 were identical in design. They were divided internally into two pen segments (Figures 10.2 and 10.4). Each segment contained twenty animals. The animals in Segment 1 were so placed as to permit the study of animal translation; those in Segment 2 were so placed as to allow the study primarily of the effect of military field equipment as secondary missiles. These missiles were placed on the ground inside the forward fence in line with Segment 2. They consisted of some of the items of standard equipment of an infantry platoon in combat. Each piece of equipment was individually labeled, weighed, and its profile cross-sectional area determined prior to placement.

No provision for predetermined animal orientation was made. No method to ensure ambulation prior to the shot was made.

Stations 2 and 3 had foxholes, 18 by 36 by 36 inches deep. In each was placed a single pig weighing approximately 50 pounds.

10.4 OPERATIONS

The animals were placed at 2400 hours on D−1 day. Each animal number (ear tag) was recorded as the pig was placed, providing specific knowledge of the station and segment location of each animal prior to the shot.

Following the shot, recovery began as soon as the area could be entered. Stations 5, 4, 3, 2, and 1 were entered in this order at H+4, 4½, 5, 11, and 11 hours, respectively. Triage was carried out, and the living seriously wounded animals were immediately evacuated to the hospital, 7 miles to the south. Individual clinical records were initiated and maintained for each animal. This record describes all wounds incurred, missile tracts where found, missiles recovered from wounds, animal's location at time of shot, thermal and radiation doses received, therapeutic record, clinical course, survival or sacrifice time as indicated, and post-mortem examination.

Photographic documentation was obtained at each station, both prior to and after the shot. Where significant wounds were found, they were photographed before the evacuation of the animal, as well as in the operating and autopsy suites. Whole-body diagnostic roentgenograms were obtained where necessary. For details of the wound analysis, see Chapter 7.

The previously placed missiles were recovered as completely as possible, and the total distance of translation was recorded.

10.5 INSTRUMENTATION

A thermal dosimetry line was provided by Project 8.2, consisting of both thermal radiant energy meters and skin simulants at the front stake of each station (1 through 5).

Radiation dosimetry consisted of 200 NBS film packs of appropriate dose range for pigs at ranges between 2,500 and 4,000 feet (Program 2), and instrumentation at each of two stations located between 2,100 and 3,900 feet along the pig array. The instrumentation included NBS total gamma (Program 2), Sigoloff neutron total dose, and two data points from neutron threshold detectors (Program 39).

Blast measurements were provided by DOD Project 1.1 from Stations 1 through 5.

10.6 RESULTS

The calculated and observed blast and the thermal radiation levels are presented in Tables 10.1 and 10.2.

Where the condition and position of the animal at recovery indicated that the animal had been translated by the blast from its original pen segment to a specific site and had not moved thereafter, the total distance of translation was recorded (Chapter 7). No knowledge of trajectory was available.

Postshot photographs of the stations and representative injuries are presented in Chapter 7, as well as in Figures 10.5 through 10.9.

10.7 DISCUSSION

10.7.1 Instrumentation. The measured blast parameters are in satisfactory agreement with the predicted values. The precursor effect terminated between Stations 3 and 4, as anticipated. The levels of thermal radiation as measured were somewhat below the predicted levels but, nonetheless, were high (as predicted).

10.7.2 Wound Analysis. The most significant general observation concerning biological effect at Stations 1 through 5 was the abrupt termination beyond Station 3 of death due to the trauma of translation. Because of the precursor effect, the dynamic pressure fell abruptly from 13.0 psi at Station 3 to 1.9 psi at Station 4. Thus, at Stations 4 and 5 the cause of death, in general, was radiation plus burn; while at Stations 1, 2, and 3, death was, in nearly all cases, almost instantaneous—due to translation of the animals at very high velocities by the blast. The wound analysis is given in Table 10.3.

When the recovery party entered Stations 1 and 2, all animals had been blown completely out of the exposure pen, and the enclosure fence no longer existed. All animals had apparently been killed almost instantly, and the animals from Station 1 had been translated beyond Station 2. The single exception was Pig Number 513, which had been placed in a foxhole within Station 2. This animal, on recovery, was still in the foxhole and was conscious. In the truck enroute to the hospital, convulsions typical of central-nervous-system radiation death were demonstrated. The animal survived 6 hours, showing anorexia and lassitude during this period. Autopsy showed no burns, mild atelectasis, subscapular splenic hemorrhages, subserosal petechial hemorrhages of the ileum, and congestion of the stomach and mesenteric nodes.

At Station 3, the primary cause of death was again found to be mechanical injury due to translation. Only six animals survived the blast. One occupied a foxhole within the enclosure; this animal survived 91 hours. Of the five others, four were from the rear segment of the pen and most likely had struck the rear fence, thereby limiting their maximum velocity.

At Staton 4, the closest station outside the precursor, 36 of 39 animals survived the immediate weapon effects. The earliest death from radiation and burns occurred at H+7 hours, while the longest survivor lived 133 hours. The cause of death in the immediate survivors was radiation injury plus contributory severe burns.

At Station 5, all animals survived the initial period. Three dosimeter animals are not included in the totals. The longest survivor lived 167 hours; the earliest death occurred at 47 hours. The cause of death in all animals was radiation injury plus severe burns.

10.8 CONCLUSIONS

For a large biological specimen in the open, within the precursor from a nuclear weapon, the primary cause of death is mechanical injury to the organism due to translation, and the percent killed instantly is nearly 100.

Outside the precursor, temporary survival may be expected in the open (barring total missile injury), but the radiation levels at these ranges are so great that early death will invariably ensue.

A foxhole will provide sufficient protection to prevent total injury from blast and burn, but the radiation shielding is inadequate. Although the survival time will be slightly longer, a lethal dose of radiation will ultimately be the cause of death.

TABLE 10.1 EXPOSURE STATIONS, SHOT PRISCILLA

Station Number	Outside Dimensions	Number of Animals	Maximum Peak Overpressure		Peak Dynamic Pressure	
			Predicted	Measured	Calculated	Measured
	ft		psi	psi	psi	psi
1	10 × 20	20	11.8	10.0	50	26.3
2	10 × 20	20	10.0	9.9	—	22.0
3	35 (diameter)	40	8.4	9.8	20	13.0
4	35 (diameter)	40	8.0	9.2	2.3	1.9
5	35 (diameter)	40	7.5	8.5	1.4	1.4

TABLE 10.2 CALCULATED AND MEASURED THERMAL AND RADIATION DOSES

Station Number	Initial Gamma Dose		Neutron Dose		Calculated Total Dose	Thermal Dose	
	Calculated	Measured*	Calculated	Measured		Calculated	Measured
	r	r	rep	rep	rep	cal/cm^2	cal/cm^2
1	2,370	12,100	13,000	8,700	15,370	135	85
2	1,980	10,200	10,580	7,200	12,560	130	82
3	1,273	6,500	6,070	4,290	7,343	100	75
4	308	1,490	1,030	770	1,338	57	53
5	224	1,070	696	525	920	50	49

* Chemical dosimetry, air dose.

TABLE 10.3 WOUND ANALYSIS, STATIONS 1 THROUGH 5

Station Number	Total Number of Animals	KIA*	Mean Survival Time†	Dosimeter Pigs
			hr	
1	20	20	0	0
2	20	19	6‡	0
3	40	34	52§	0
4	39	3	86	0
5	40	0	90¶	3

* Animals killed outright or dead on recovery.

† Mean survival time of animals living at time of recovery, excluding those in Category KIA.

‡ One animal in foxhole.

§ One animal in foxhole lived 91 hours and is excluded from Mean Survival Time calculation.

¶ Does not include three dosimeter pigs.

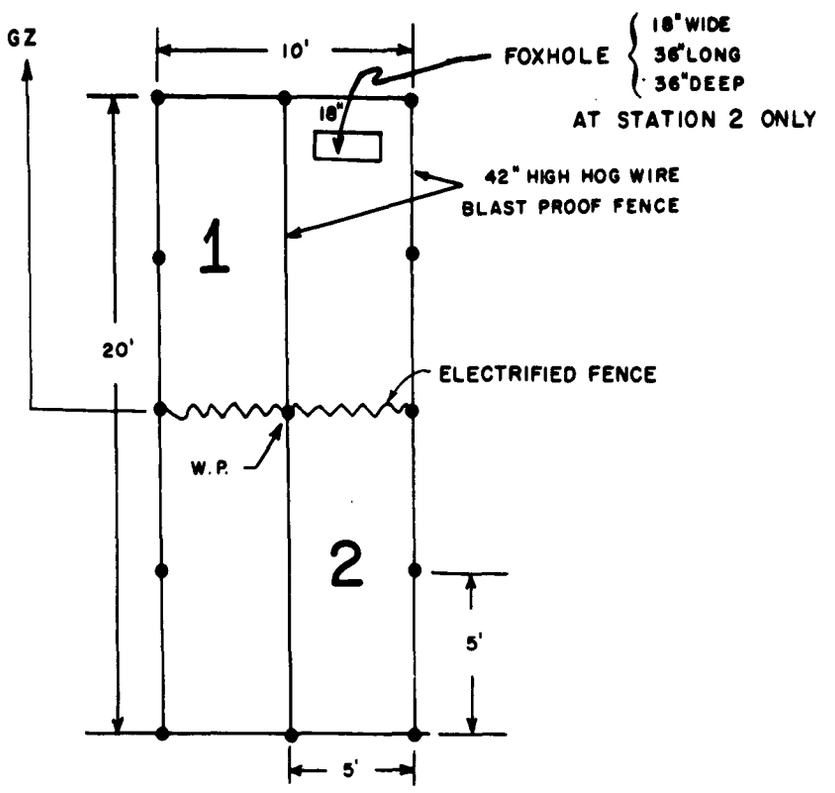


Figure 10.1 Schematic drawing of Stations 1 and 2.

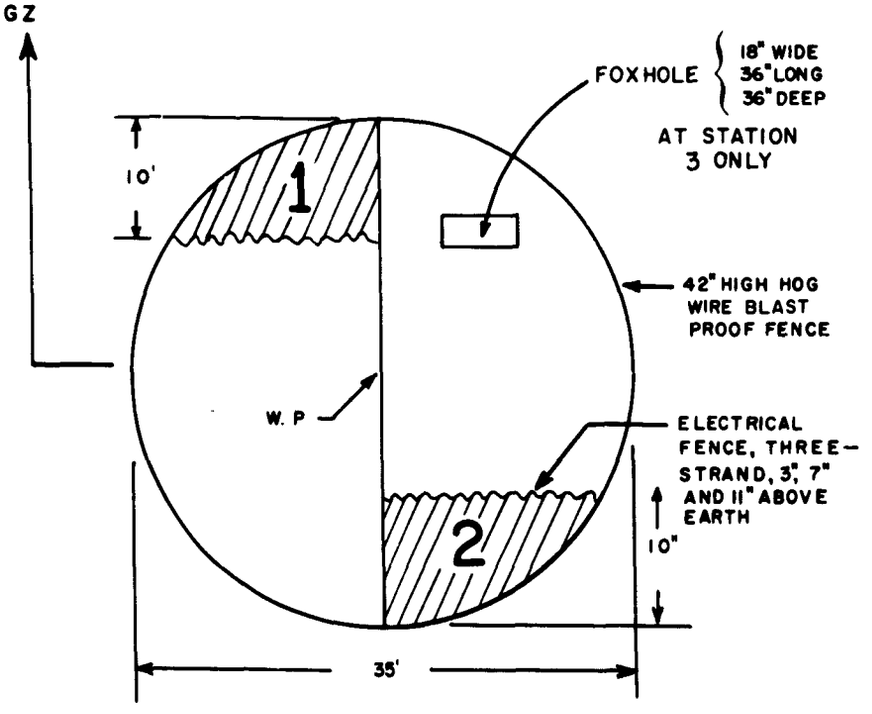


Figure 10.2 Schematic drawing of Stations 3, 4, and 5.

Figure 10.3 Preshot view of Station 1, Shot Priscilla.

Figure 10.4 Preshot view of Station 3, Shot Priscilla.

Figure 10.5 Postshot view of Stations 1, 2, and 3; arrows indicate animal displacements, Shot Priscilla.

Figure 10.6 Postshot view of Station 4, Shot Priscilla.

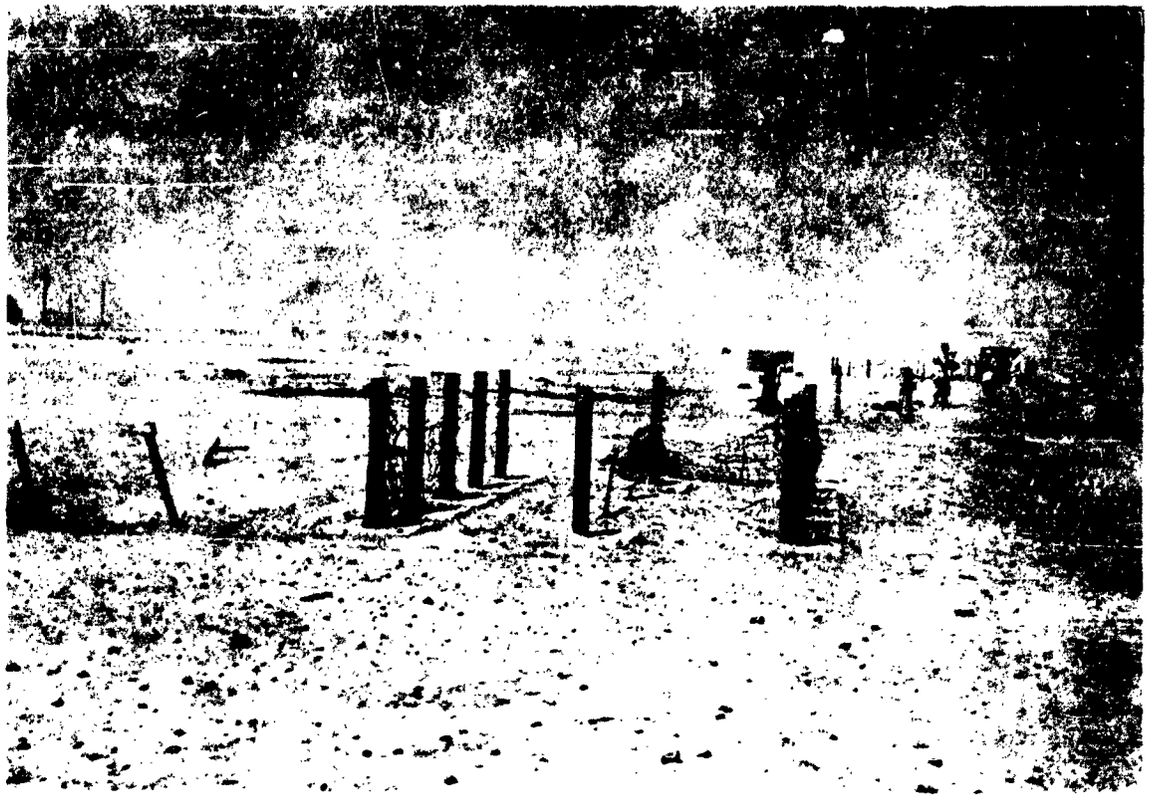


Figure 10.7 Postshot view of Stations 1 and 2 looking away from ground zero, Shot Priscilla.

Figure 10.8 Postshot view of Station 4.

Figure 10.9 Postshot view of Station 5.

Chapter 11

SUMMARY

The data derived from this experiment was obtained by placing the living specimen in many environments, some of them extremely artificial, for the sake of the experiment. The most obvious planned environment was the fixed-mount window glass in order to obtain thoraco-abdominal wounds. It is apparent that this is not a typical battlefield environment; in fact, few urban areas duplicate these parameters of placement.

11.1 EXTRAPOLATION OF DATA TO HUMANS

It was hoped that the biological data would subject itself in many cases to humans. This has been covered in Chapters 2 through 7. These extrapolations are summarized below.

The median-lethal dose of nuclear radiation (486 ± 10 rep) was more than twice that previously observed at a nuclear test. A similar trend in humans appears to be in order with reanalysis of the Japanese data.

Failure of the device to produce the predicted performance caused a loss in determination of relative biological efficiency of neutrons in producing lethality.

The radiation syndrome observed and the median survival times were similar to other mammalian species after comparable exposure doses.

A 2-year followup study of the survivors of the test series shows no untoward effects, and a limited breeding program fails to disclose genetic abnormality.

In spite of pretest predictions that the pig would not show a mortality response to blast and burn, the animal did show morbidity and mortality when exposed to the combined effects of a nuclear device.

In animals wounded, or burned and wounded, the clinical healing of the wounds or burns appeared to be little influenced by irradiation, except at lethal levels. In those animals which received supralethal levels of radiation, the burns were dry and grossly healing uneventfully at death (this probably will not apply in humans).

Combined injury—whole-body radiation plus wounds and/or burns—results in a definitely shortened survival time over that of the animal exposed to comparable levels of radiation alone.

The median lethal value of nuclear radiation was approximately 100 to 125 rep lower for animals exposed to all effects of the device rather than to the radiation alone.

When the living specimen is exposed in the open within the range of the precursor, there is virtually 100 percent mortality either from dismemberment or severe translation.

A foxhole within the precursor will protect against the precursor effect and line-of-sight thermal but not necessarily against ionizing radiation.

Blast-translated battlefield debris is not an important source of casualties except in the precursor where it is an incidental finding and thus of no clinical significance.

Analysis of the fate of a living specimen (human) in various environments, such as tank interiors or machine-gun emplacements, has been shown to be done more accurately and realistically by exposing the animal along with test gages or devices.

Dominant injury versus distance for Shot Priscilla is given in Chapter 7. For this device under these conditions of detonation, ionizing radiation was the decisive injury in nearly all casualties. This generality cannot be made in all tactical or combat detonations.

The bacteriology of the swine in health and disease, as well as in the postshot period, was studied extensively (Chapter 4). Pathogenic Clostridia were present in many of the wounds, but disease did not result; this can be explained by the resistance of the swine to Clostridia and the absence of tissue crushing. Salmonellosis did not occur in the postshot period. The most frequent invading organism was Pasteurella multocida which is a respiratory organism rather than a habitant of the gastrointestinal tract. This represents a variance from the findings during previous operations.

The administration of spleen-bone marrow homogenates did not alter the mortality of the gamma-neutron irradiation in the test animals. Possible explanations and mechanisms are given in Chapter 5.

11.2 OPERATIONAL CONCEPTS

Certain operational concepts have been derived from this experiment. Because these will result in more accurate evaluation of nuclear weapon casualties, therapeutic procedures will be improved.

Medical officers who observed the animals in the early postshot period gave a rapid and accurate portrayal of the dominant injury. However, they were unable to accurately define the extent or degree of thermal injury, difficult enough in the swine in the laboratory, but doubly so in the field because of the extensive dust clouds that coated every object. Further, the combat physician intuitively recognizes the injury that requires immediate therapy, in this case the mechanical wounds.

The ionizing-radiation syndrome was not recognized in the early postshot period, because there were no signs or symptoms. Triage of casualties is properly done upon the observation and evaluation of the presenting signs and symptoms.

A new method of doing total leukocyte counts, the pinhead count, was devised and field tested (Chapter 5). It is the most expeditious and accurate means for qualitative analysis of exposure to clinically significant doses of ionizing radiation.

11.3 EXPERIMENTAL DESIGN

Experimental design was vindicated in this project. Wounds were obtained as desired and the clinical program was executed as planned. The swine was determined to be a suitable test animal for field testing.

Appendix A

PILOT STUDY, SHOT WILSON

Because of the many physical and operational problems involved in Shot Priscilla, a pilot study was deemed advisable in advance of this shot. The objectives were the evaluation of the missile design for Priscilla and the provision of an opportunity for a preliminary test on a small scale of the operational capability of the recovery teams to be employed during Shot Priscilla. This pilot study was carried out on one axis from the Wilson device, an axis separate from the radiobiological program (Chapter 2).

A.1 PROCEDURE

Four exposure stations were employed, placed at levels of peak overpressure corresponding to the four major installations for Priscilla. Each exposure pen measured 10 by 30 feet, the long dimension along the blast line. A glass-pane installation identical to that used for Priscilla Stations 6, 7, 8, and 9 was used as a missile source; but the ten swine at each exposure station were staked out, unanesthetized, along a diagonal line extending from a point 7 feet from the northwest corner of the pen to the southeast corner. Eight animals were staked along this line, at 3-foot intervals, their heads facing away from ground zero. Two additional animals were placed on an elevated table, similarly oriented, behind the diagonal line just described (Figures A.1 and A.2). The table was 16 inches in height, and the surface measured 16 by 72 inches. The table was immobilized by being affixed to six steel stakes driven 24 inches into the ground at each leg. In addition, the stakes to which the pigs on the table were tied passed through holes in the table, adding further to the immobilization of the table.

This arrangement located the animals at varying distances from the glass installation. The objective of this plan was to evaluate the effect of the distance between the target and the missile source on the missile velocities and resulting wounds in the specimens. The animals placed on the elevated table gave qualitative information regarding missile trajectory.

At each exposure station, a Styrofoam trap was placed in the center of the pen adjacent to the rear fence. The trap was sandbagged on all sides including the top surface, except for the front exposed face of the Styrofoam. Two steel cables secured to deadmen crossed the top of the trap. The rear surface of the trap with one layer of sandbags intervening lay against the steel pipe fence post in the middle of the rear of the pen. The Styrofoam was 23 inches thick, consisting of 23 1-inch layers of special order Styrofoam 22. The functional area of the Styrofoam measured 22 by 22 inches. The overall dimensions of the trap were $32\frac{1}{2}$ inches wide by 29 inches high by $32\frac{1}{2}$ inches deep. A layer of aluminum foil over the front surface of the Styrofoam provided thermal shielding. The purpose of the trap was to collect missiles from the installation, for evaluation of their mass and velocity distribution.

Thermal instrumentation was provided by Project 8.2. It consisted of thermal radiant-energy meters placed between 2,500 and 4,000 feet. The range covered was 18 to 35 calories cm^2.

Radiation dosimetry was provided by CETG Program 39 and consisted of: (1) neutron measurements using the fission-foil system of Hurst, including gold, cadmium-covered gold, sulfur, neptunium and plutonium foils; (2) gamma-ray measurements using the chemical dosimeter system developed by Sigoloff; and (3) midline dosimetry by internally placed Sigoloff dosimeter between 1,300 and 1,425 yards from ground zero. Gamma dosimetry was also provided by Project 2.6.

Measurements of blast overpressure, dynamic pressure, and pulse duration were provided by DOD Project 1.1.

Documentary photography was obtained during placement and recovery. Individual clinical and therapeutic records were kept on each animal. All animals were autopsied after death.

A.2 RESULTS

The results are presented in Tables A.1 and A.2. All Styrofoam traps were recovered in excellent condition. Log-log plot of the mass versus the velocity of each missile and linear plots of the spatial distribution of the missiles at each station are given in Figures A.3 through A.11. The lower margin of the Styrofoam lies $3\frac{1}{2}$ inches above the earth (Figures A.4 through A.7). Representative photographs before and after the shot are presented in Figures A.12 through A.16.

All animals were recovered alive; in each case the animal was still held in position by the restraining harness. Evidence of rope burns at the points of contact of the harness was seen in a number of cases. On the exposed side, the rope also caused exfoliation of the burned skin in the areas of contact. No wounds were found that had penetrated either the parietal pleura of the thorax or the peritonium. The predominant visible injury was extensive burns of the exposed surfaces.

A detailed wound analysis on each animal is presented in Table A.3.

A.3 DISCUSSION

The criteria for wound evaluation were established arbitrarily. Because no wound was found that penetrated the peritoneum or the parietal pleura in the thorax, the number of penetrating wounds is considered to be zero. The superficial wounds were then classified as shown in Table A.3. This permits at least partial analysis of the data in terms of missile effect on the target.

The data pertinent to discussion and analysis is collected for convenience of reference in Table A.1. It is immediately evident that no penetrating wounds of the peritoneum or of the parietal pleura could have been expected because the mean velocities were much too low. Reference to Figures A.8 through A.11 shows further that at Stations 12, 13, 14, and 15 only 3.3, 22, 7.1, and 0 percent, respectively, of those missiles recovered from the trap had velocities greater than 150 ft/sec. At Station 13 only, 4 percent of the missiles had a velocity greater than 200 ft/sec. The statistical probability of obtaining penetrating wounds under these circumstances is vanishingly low.

Because the experimental design was also such that only four of each ten animals were at an optimum distance from the glass array to incur significant wounds, the probability of obtaining such wounds was further reduced. Because so few wounds per animal were

obtained, no conclusion can be drawn with respect to wound incidence versus distance from the glass array, although the tendency suggests that Positions 4 and 5 (Table A.3) incurred more wounds. This, however, may have been caused by a greater missile density opposite the central portion of the glass array. This interpretation is further limited by loss of the placement list for Station 13.

With respect to a possible upward trajectory of the glass missiles, again the small number of wounds does not permit a conclusive comparison between the animals on the elevated tables and those at ground level.

The animals exposed in this experiment weighed from 60 to 90 pounds. The theory as developed in pretest missile studies applies to animals weighing between 40 and 60 pounds. Hence, the additional thickness of skin and muscle in these larger animals tended further to minimize the effect of the missiles.

It is noted that the mean mass of the fragments increases as the peak side-on overpressure decreases. This is consistent with the theory and with previous study in glass fragmentation. The mean velocity is greater at Station 13 than at Station 12, and then steadily decreases with decreasing peak side-on overpressure. This apparent anomaly is also consistent with the theory and with previous experience. The explanation apparently lies in the size of the fragments. As the peak pressure decreases, the fragment size increases. Up to a certain size, glass fragments act essentially as spheres, with a drag coefficient near unity. Beyond this limit, larger fragments no longer behave as spheres, and those which are oriented with their flat surface normal to the blast winds have drag coefficients significantly greater than 1.0 and, consequently, experience a greater acceleration and attain a higher terminal velocity. As the pressure becomes still smaller, the effect of the slower drag winds predominates, and the velocities again decrease.

The analysis of superficial wounds shows that the greatest number of wounds occurred at Station 13 as would be expected from the missile analysis.

The fact that higher velocities were not obtained is unquestionably due to the short pulse duration and the resultant rapid decrease in the velocity of the winds following the shock front. The longer pulse in a higher-yield weapon would result in greater missile velocities being obtained at the same levels of peak side-on overpressure.

Reference to Figure A.17 and to Figures A.4 through A.7 emphasizes the fact that, in this study, the Styrofoam traps were obstructed by the animals, which were placed in front of the traps at a distance of 8 feet. Hence, many missiles that might have embedded in the trap were stopped by collision with the animals. The concentration of missiles above the middle of the trap may be due to an upward trajectory, and it is probable that most of the glass fragments passed over the animals. Mean survival time and percent of total-body burn is included in Table A.1 for completeness. The biological results of the present experiment are discussed in Chapter 8 (Section 8.2).

A.4 CONCLUSIONS

The results obtained in the pilot study are consistent with the theory. Because the probabilities of penetration are low for a larger weapon (Priscilla), it is not surprising that no penetrating wounds were obtained in the present experience. This does not alter the results predicted from Shot Priscilla, because the longer positive pulse, the greater number of smaller animals, and the relatively infinite extent of the glass array should result in higher velocities and a significant number of severe wounds, including penetrating wounds of the thorax and abdomen.

Because the possibility of an upward trajectory of the missiles is considered possible, it was concluded that the 6-inch gap at the bottom of the glass array should be filled in with glass in the Priscilla installation.

TABLE A.1 COMBINED MISSILE-WOUND ANALYSIS, SHOT WILSON

P_s, peak side-on overpressure; q, peak dynamic pressure; t_+, duration of positive pulse; GMM, geometric mean mass of fragments; σ_{gm}, standard deviation of GMM; GMV, geometric mean velocity; σ_{gv}, standard deviation of GMV.

	Station			
	12	13	14	15
P_s, psi	7.1	6.6	6.0	4.8
q, psi	1.3	1.1	0.9	0.6
t_+, msec	546	554	565	596
GMM, grams	0.527	0.632	0.831	2.016
σ_{gm}, ft/sec	0.092	0.149	0.505	1.64
GMV, ft/sec	114.4	132	117	96.5
σ_{gv}, ft/sec	2.56	4.18	3.46	5.44
A*	7	18	5	2
B*	18	22	6	5
C*	2	0	1	0
Thermal dose, cal/cm^2	27.5	30.5	23.5	20.5
Mean burn, pct*	22	26	23	20
Mean survival time, hr	30	37	68	89
Gamma dose, rep	5,650	4,500	3,280	1,320
Neutron dose, rep	9,400	7,050	4,650	1,540
Total dose, rep	15,050	11,550	7,930	2,860

* Burn: Percent of total body area; not classified as first, second, or third degree. A: Puncture wound, not penetrating peritoneum or parietal pleura of thorax. B: Laceration, minor. C: Laceration, moderately severe to severe.

TABLE A.2 MISSILE ANALYSIS, SHOT WILSON

	Station			
	12	13	14	15
Maximum peak overpressure, psi	7.1	6.6	6.0	4.8
Peak dynamic pressure, psi*	1.3	1.1	0.9	0.6
Pulse duration, msec	546	554	565	596
Thermal dose, cal/cm^2	27.5	30.5	23.5	20.5
Initial gamma dose, rep	5,650	4,500	3,280	1,320
Neutron dose, rep	9,400	7,050	4,650	1,540
Total dose, rep	15,050	11,550	7,930	2,860
Glass-trap distance, ft	25.5	25.5	25.5	25.5
Total number of missiles†	60	50	28	15
Geometric mean mass, gram	0.527	0.632	0.831	2.016
Standard deviation, σ_{gm}	0.092	0.149	0.505	1.64
Geometric mean velocity, ft/sec	114.4	132	117	96.5
Standard deviation, σ_{gv}	2.56	4.18	3.46	5.44
Total number of animals	10	10	10	10
Number of animal wounds	27	40	12	7
Number of penetrating wounds	0	0	0	0

* Calculated.

† Only the large, easily identified glass fragments were removed from the Styrofoam.

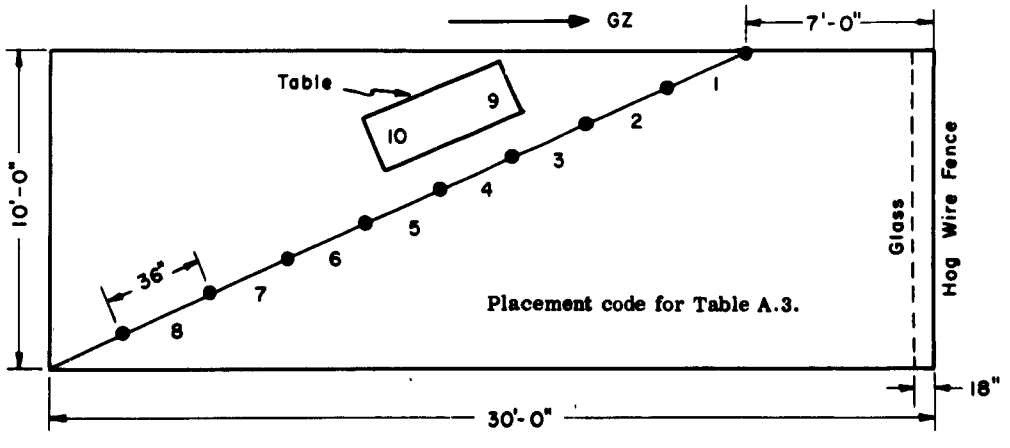
TABLE A.3 ANIMAL STUDIES

Animal Position	Animal Number	Glass-Animal Distance	Survival Time	Wound Analysis				
				Burn*	A*	B*	C*	Remarks
		ft	hr	pct				
Station 12; maximum peak overpressure: 7.1 psi.								
1	467	7.0	33	†	1	0	0	
2	466	10.0	54	†	1	0	0	
3	444	12.5	77	19	0	6	0	
4	390	15.5	33	22	2	2	0	
5	389	18.0	20	23	2	3	0	
6	468	21.0	28	†	0	0	1	Deep slicing nonpenetrating wound of abdomen.
7	442	23.5	‡	31	0	6	0	
8	451	26.5	2	†	1	0	1	Severe laceration through rectum; deep muscle laceration.
9	443	18.5	27	31	0	1	0	
10	462	21.5	47	6	0	0	0	
Station 13; maximum peak overpressure: 6.6 psi.								
Not known	12	†	55	40	3	0	0	
Placement	242	†	18	25	3	1	0	
list lost	245	†	‡	50	3	0	0	
	393	†	49	22	0	9	0	
	434	†	31	30	2	1	0	
	441	†	71	23	3	0	0	
	470	†	16	6	0	1	0	
	460	†	25	40	3	5	0	
	463	†	30	20	1	2	0	
	464	†	39	8	0	3	0	
Station 14; maximum peak overpressure: 6.0 psi.								
1	449	7.0	85	20	0	1	0	
2	450	10.0	57	20	2	0	0	
3	457	12.5	79	15	0	1	0	Back of ear.
4	432	15.5	62	25	3	0	0	
5	453	18.0	82	20	0	0	0	
6	455	21.0	41	15	0	0	1	Laceration of labia without internal injury.
7	452	23.5	81	20	0	0	0	
8	456	26.5	73	40	0	2	0	
9	445	11.5	59	23	0	2	0	
10	447	14.5	58	35	0	0	0	
Station 15; maximum peak overpressure: 4.8 psi.								
1	448	7.0	93	15	0	0	0	
2	465	10.0	96	20	0	0	0	
3	446	12.5	105	†	0	1	0	
4	398	15.5	84	10	2	0	0	
5	454	18.0	76	25	0	1	0	Nose.
6	394	21.0	84	†	0	1	0	
7	461	23.5	81	40	0	0	0	
8	459	26.5	86	15	0	0	0	
9	438	8.5	86	22	0	2	0	
10	435	11.5	95	15	0	0	0	

* Same as wound in Table A.1.

† Unknown.

‡ Hour of death not recorded.



Placement code for Table A.3.

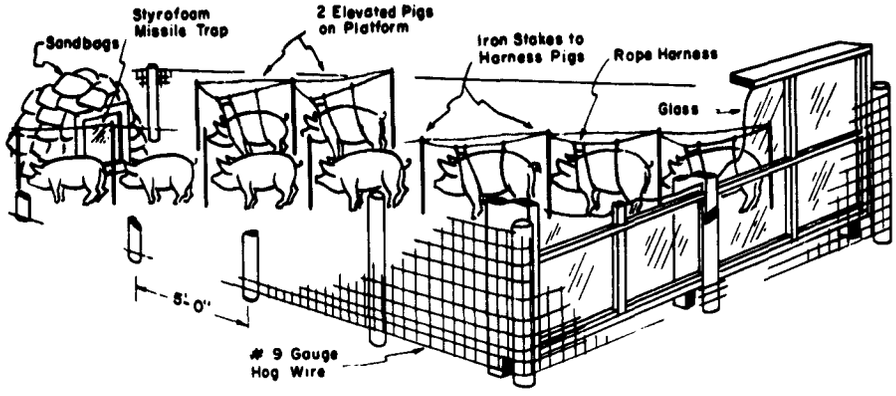


Figure A.1 Exposure pens, Shot Wilson.

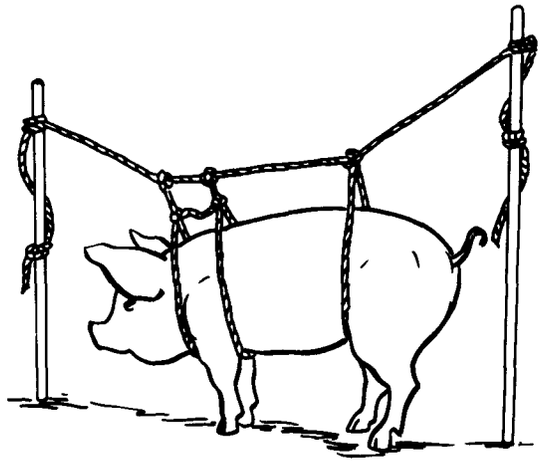


Figure A.2 Rope harness.

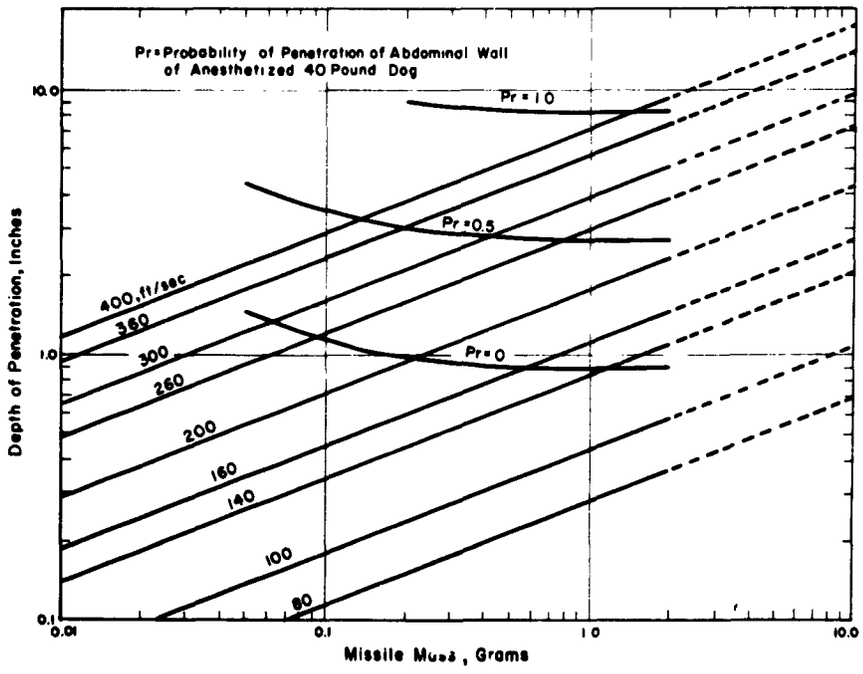


Figure A.3 Penetration for glass missiles in Styrofoam 22.

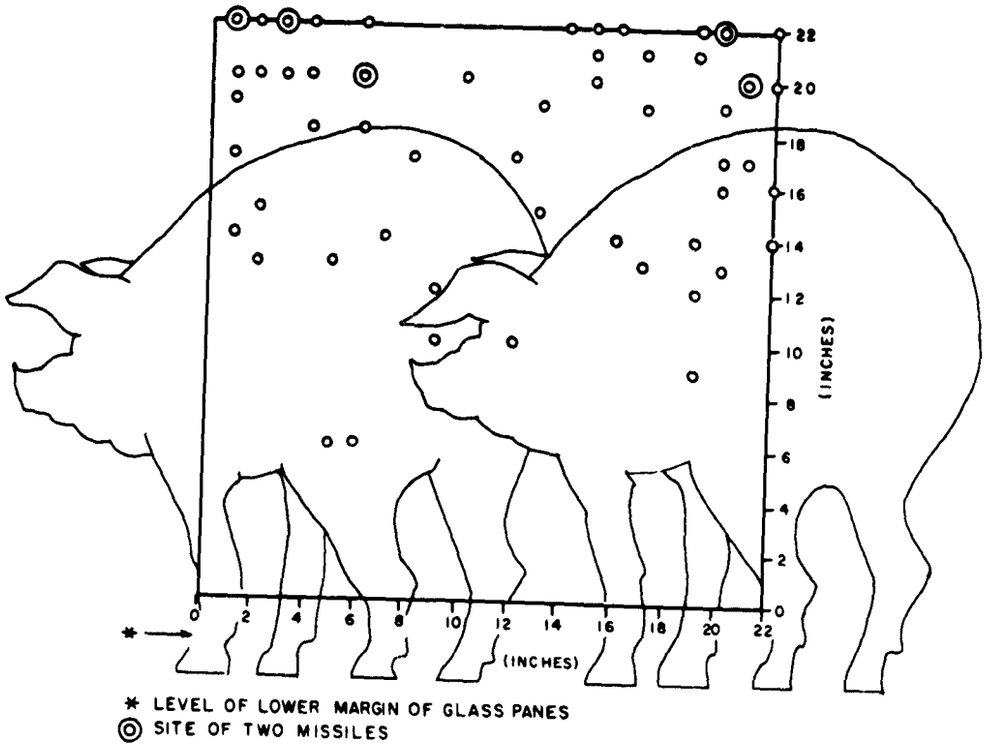


Figure A.4 Styrofoam trap, Station 12, Shot Wilson.

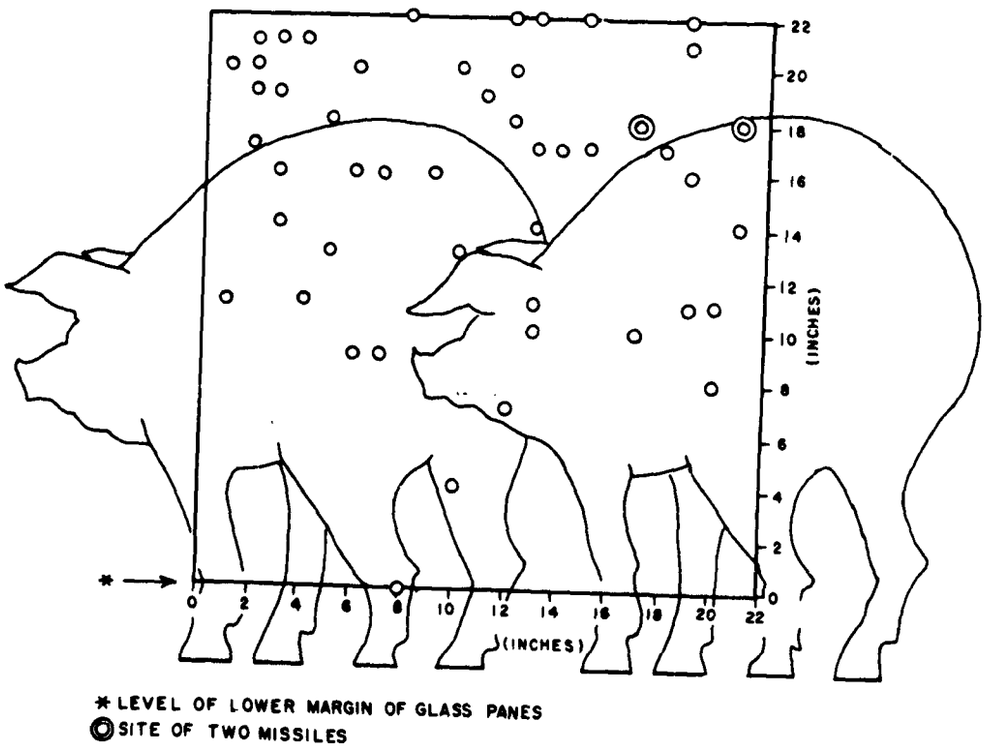
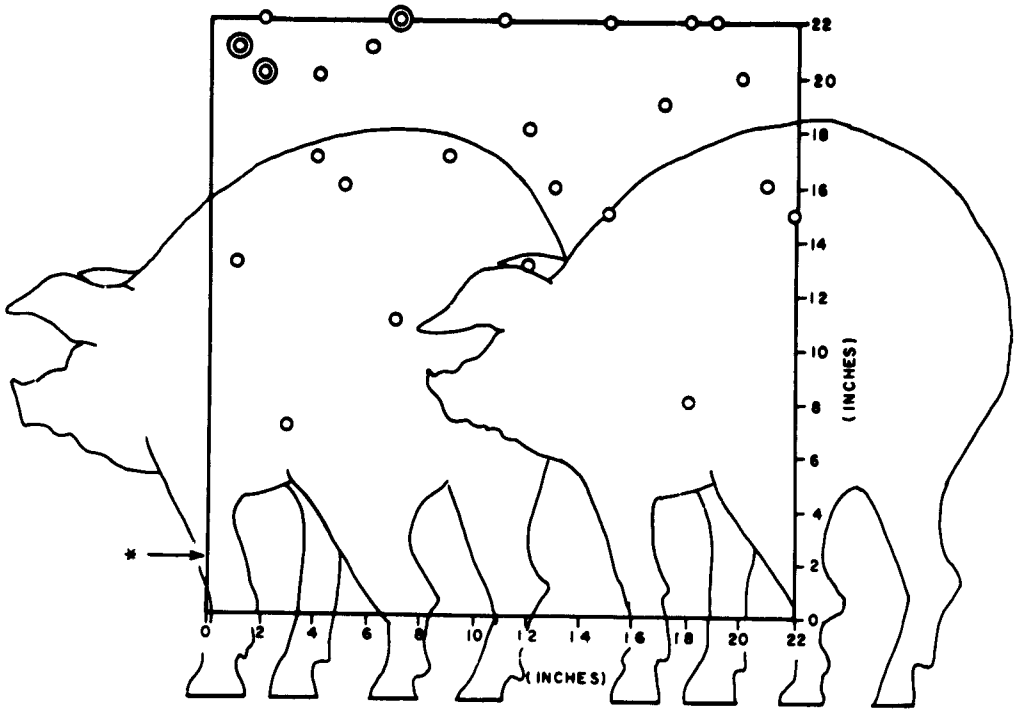


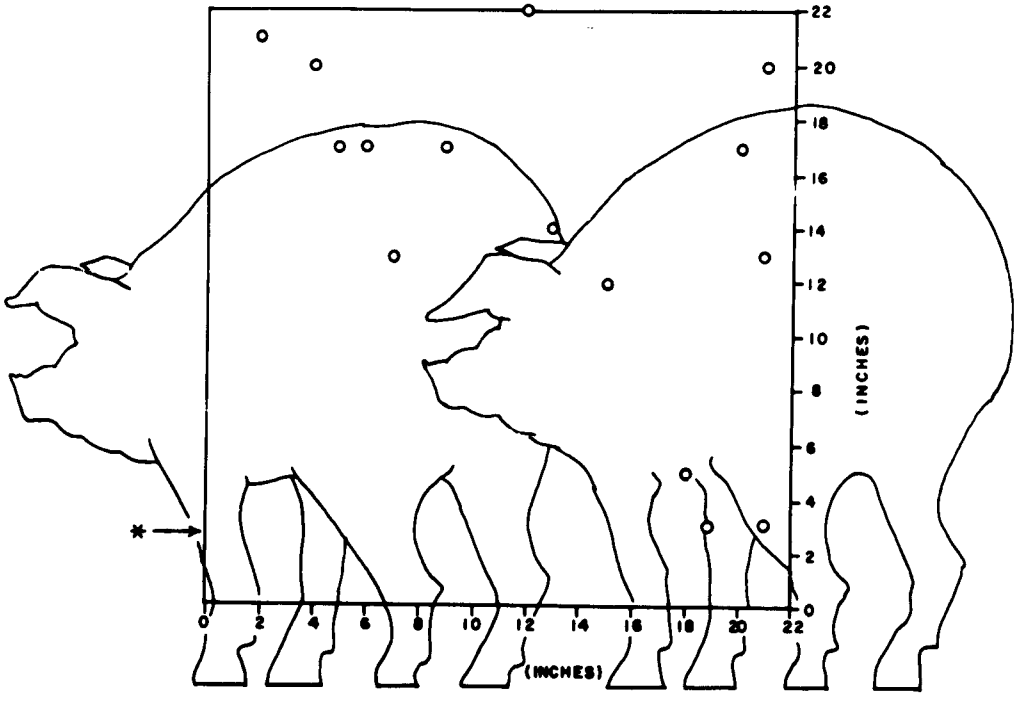
Figure A.5 Styrofoam trap, Station 13.



* LEVEL OF LOWER MARGIN OF GLASS PANES

◎ SITE OF TWO MISSILES

Figure A.6 Styrofoam trap, Station 14.



* LEVEL OF LOWER MARGIN OF GLASS PANES

Figure A.7 Styrofoam trap, Station 15.

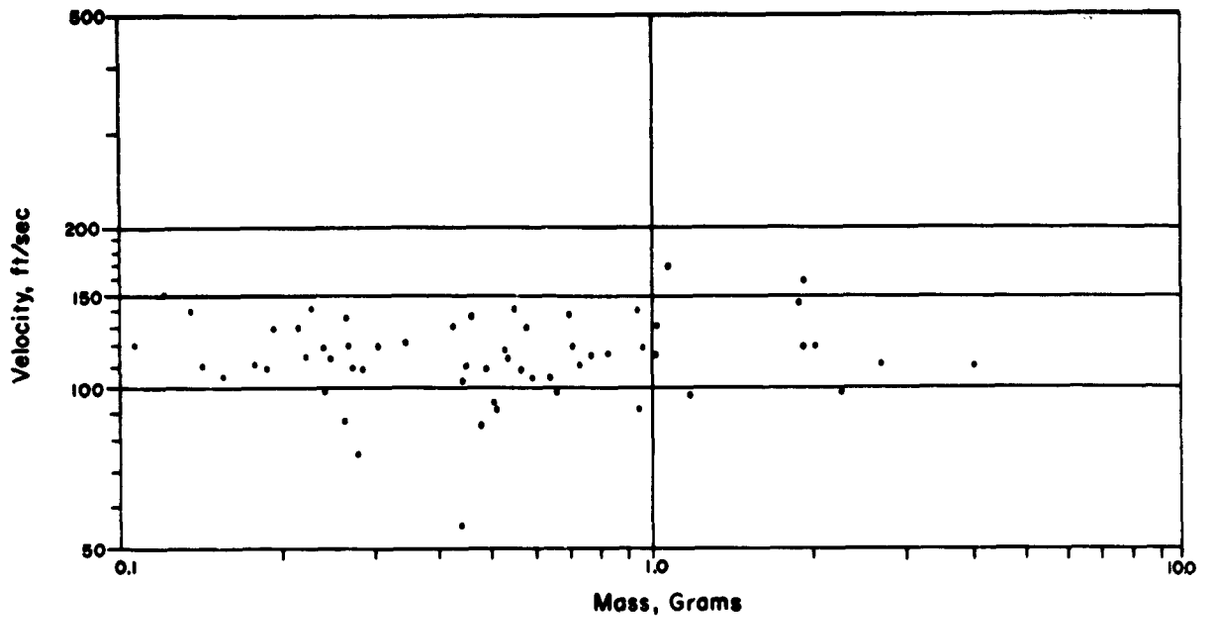


Figure A.8 Mass versus velocity for missiles, Station 12.

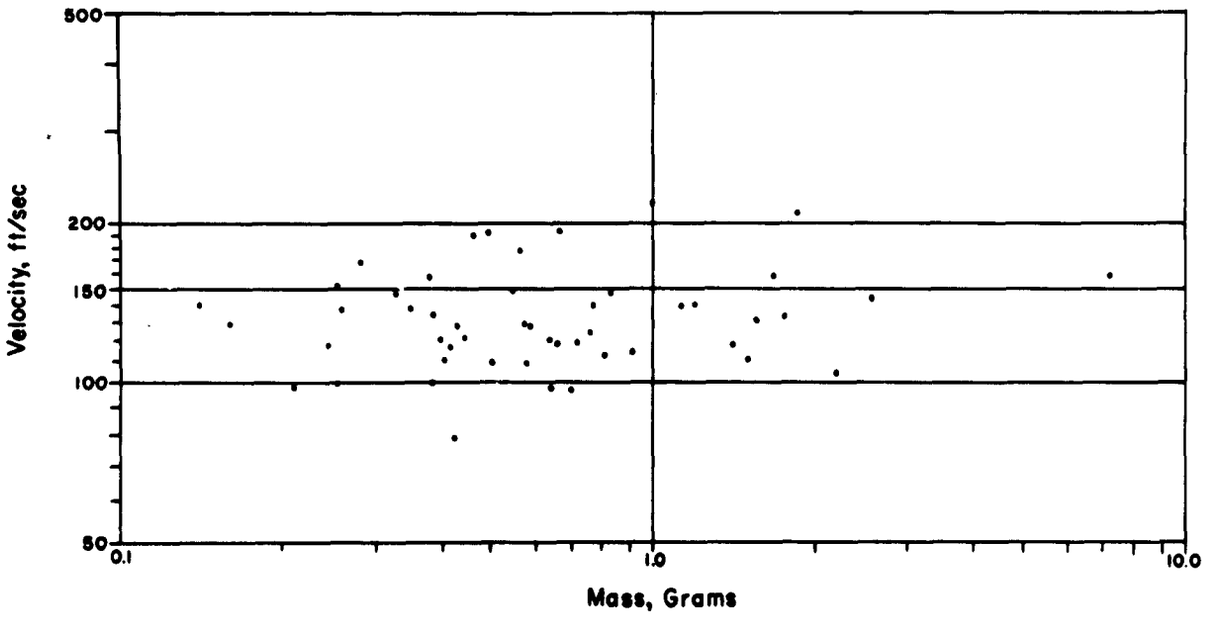


Figure A.9 Mass versus velocity for missiles, Station 13.

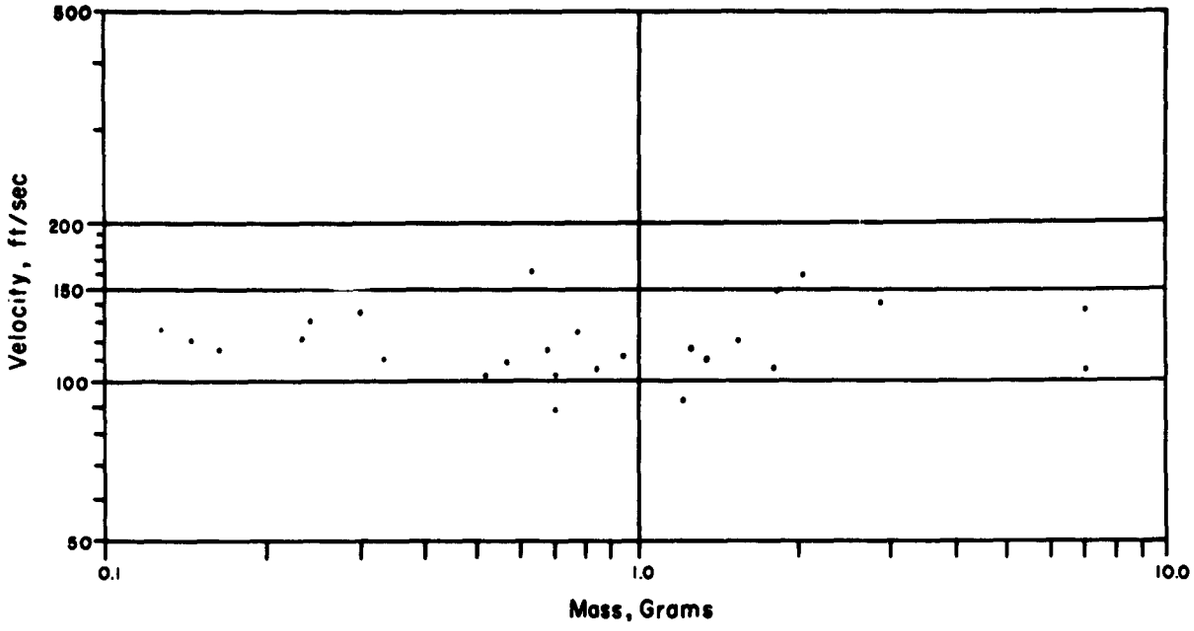


Figure A.10 Mass versus velocity for missiles, Station 14.

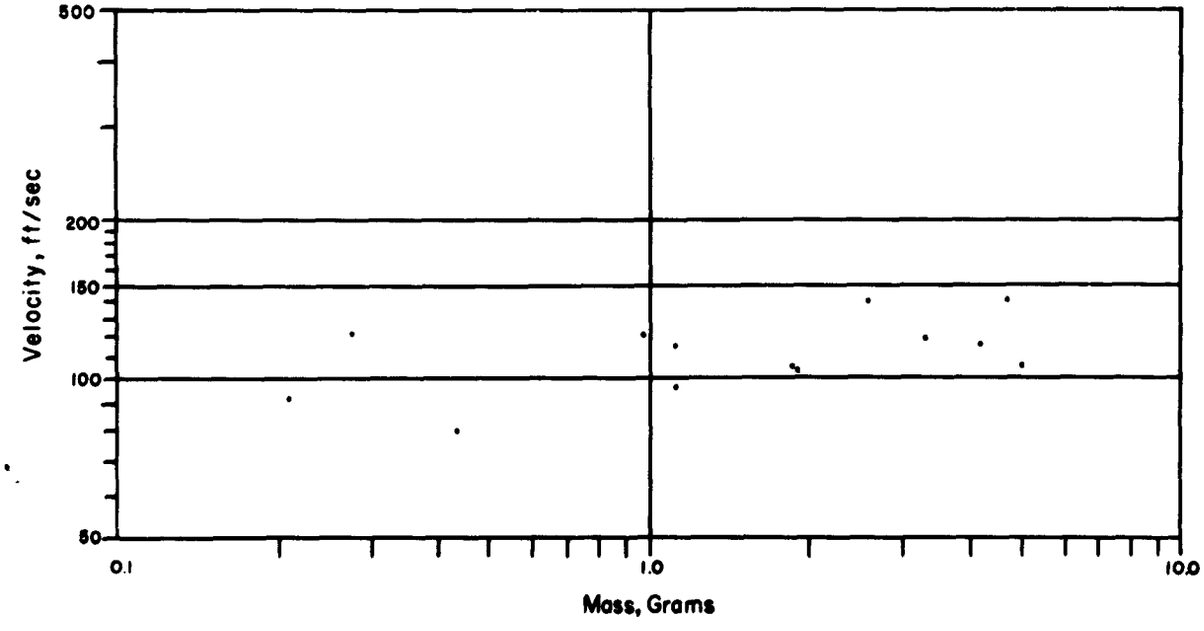


Figure A.11 Mass versus velocity for missiles, Station 15.

Figure A.12 Preshot view of Station 14 with animals in place.

Figure A.13 Postshot view of Station 12.

Figure A.14 Postshot view of Station 13.

Figure A.15 Postshot view of Station 14.

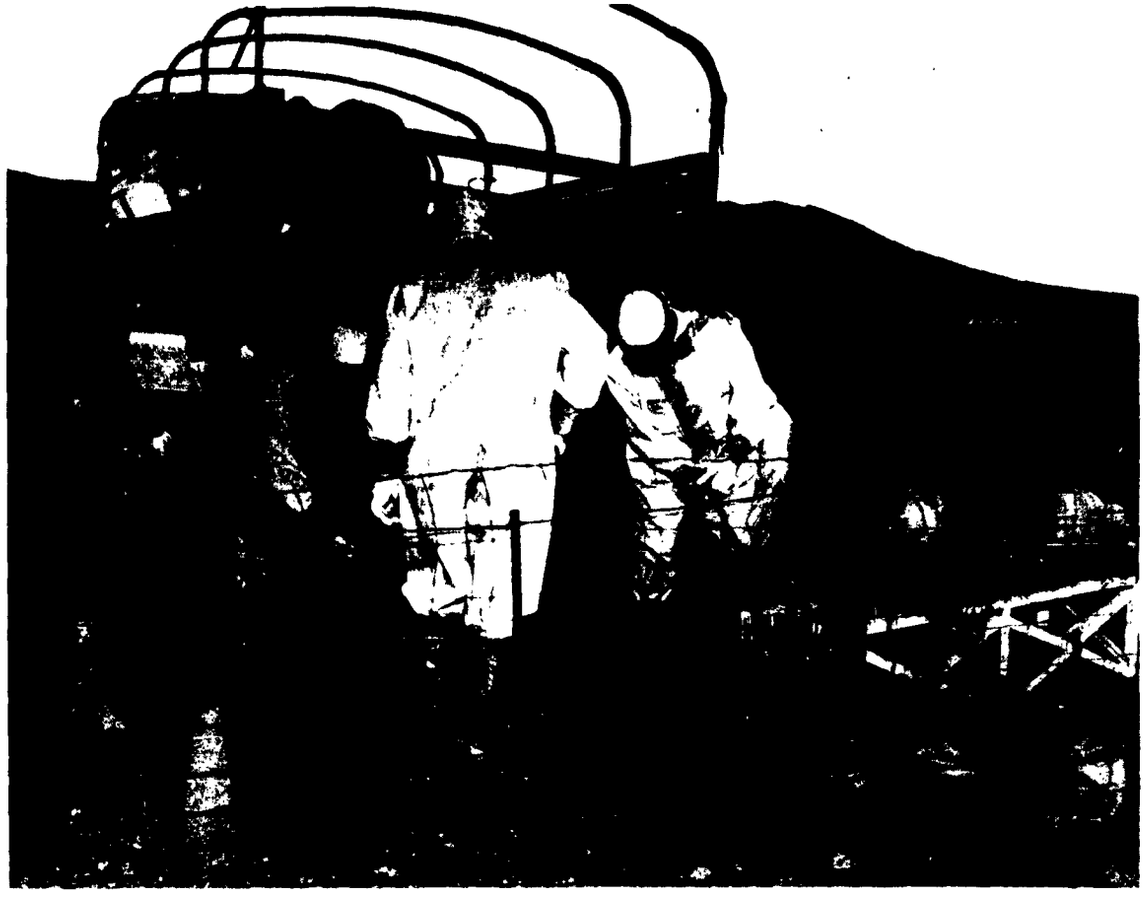


Figure A.16 Postshot view of Station 15.

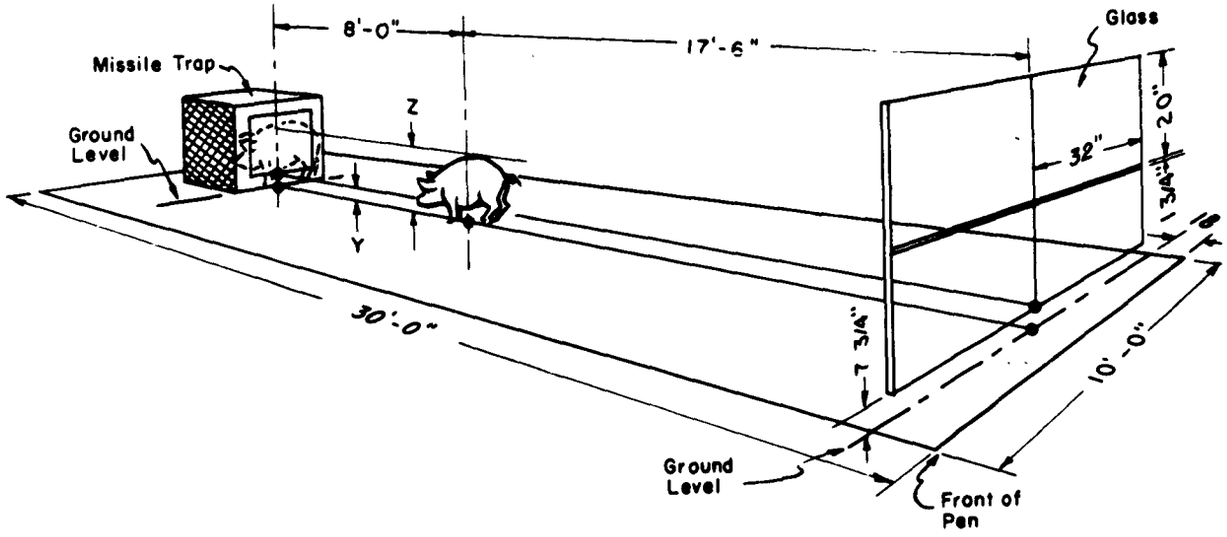


Figure A.17 Experimental design, Shot Wilson.

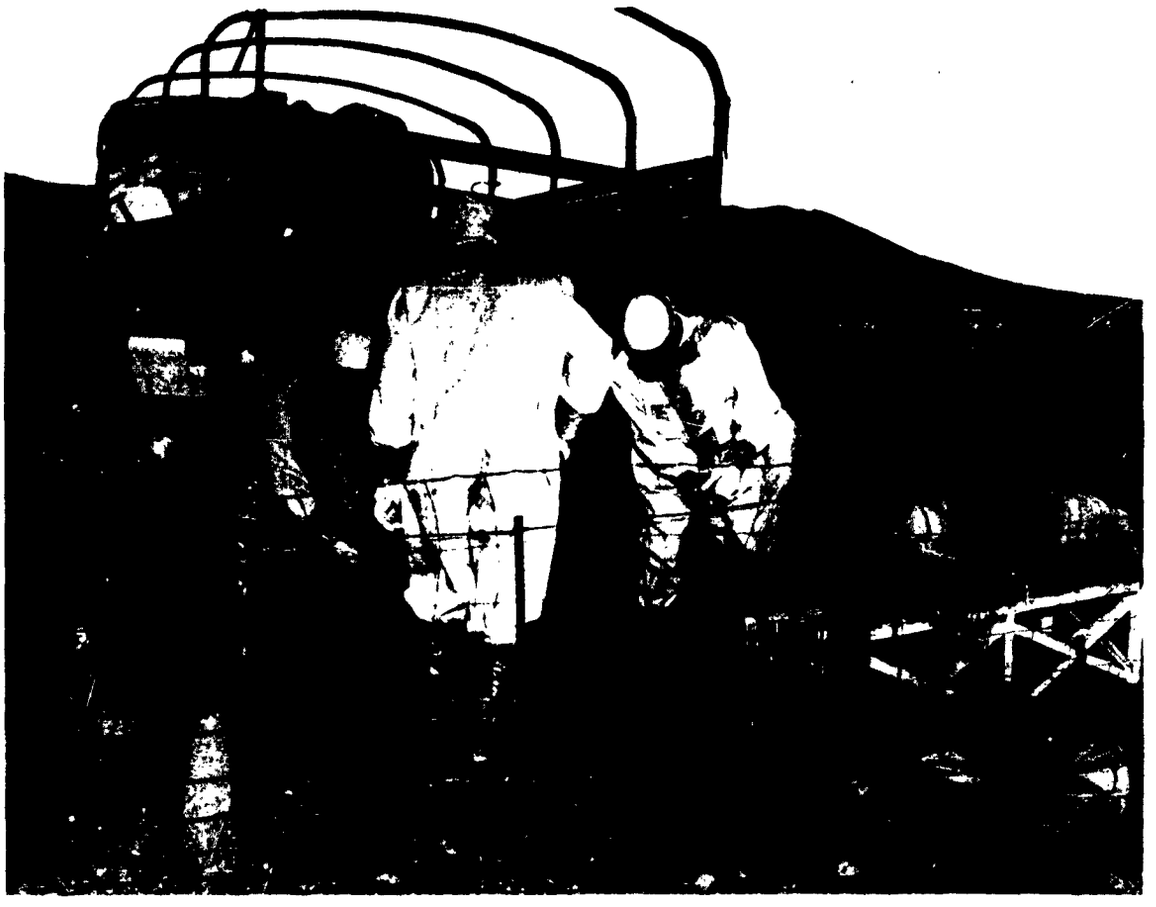


Figure A.16 Postshot view of Station 15.

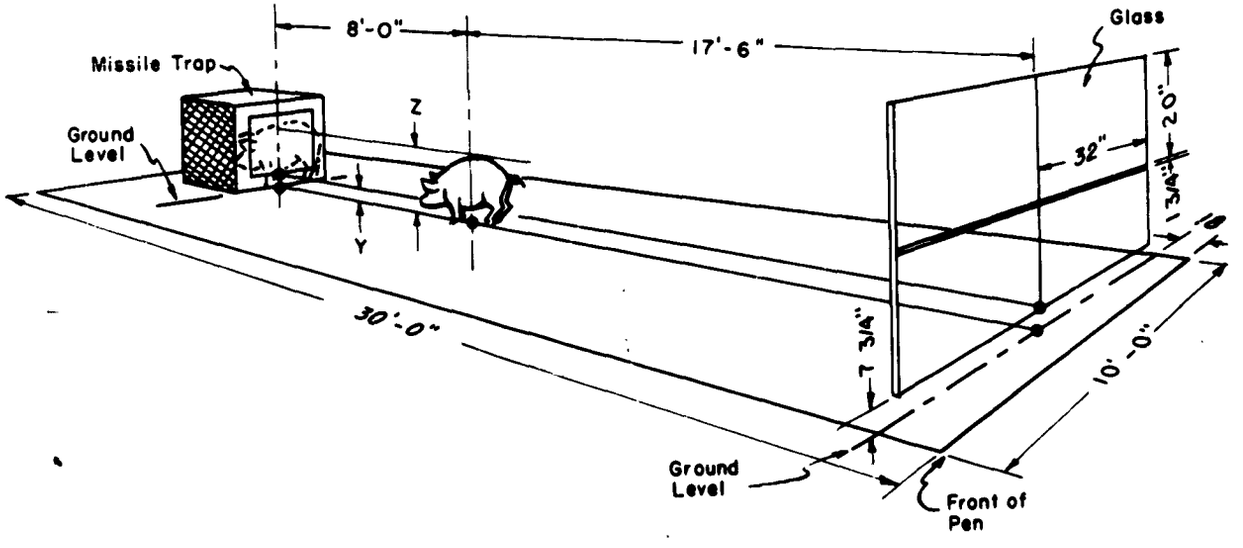


Figure A.17 Experimental design, Shot Wilson.

Appendix B

MISSILE DESIGN AND INSTRUMENTATION

B.1 OBJECTIVE

The mission of Project 4.1, Shot Priscilla, required a minimum of 100 penetrating abdominal, thoracic, or combined thoraco-abdominal wounds in the biological specimen. It was desired that these wounds be incurred randomly and simultaneously with the thermal and radiation effects from a nuclear detonation.

B.2 BACKGROUND

Glass missiles originating from window panes were chosen as the missiles to be used. The experience and knowledge of the Lovelace Foundation for Medical Education and Research were freely used; in addition, basic research was carried out in the shock tube at the Ballistic Research Laboratories (BRL), Aberdeen Proving Ground, Maryland (Section 9.1). Glass breakage, glass fragmentation, the resulting missile velocities, and the possibility of inflicting the desired wounds by this method were studied in particular.

B.3 THEORY

The results of the pretest studies, including a complete theoretical determination of the anticipated missile velocities predicted for Shot Priscilla with the design selected, indicated a certainty of obtaining a large number of wounds and a reasonable probability of obtaining the desired penetrating wound. The maximum velocities obtained in the field test at BRL—with swine as the target for glass missiles—were slightly in excess of 150 ft/sec. This velocity, as calculated theoretically from the shock-tube curves, is in reasonable correlation with the results obtained directly by measuring terminal velocities of glass missiles collected in a Styrofoam trap. By this experimental method, using six swine weighing from 40 to 60 pounds, one penetrating wound of the abdomen and a number of severe lacerations were obtained.

Inasmuch as the predicted velocities for a similar missile design during Shot Priscilla, according to theoretical calculation, were in excess of 200 ft/sec for the near exposure pens, it was concluded that, with a large number of targets and a statistically very-large number of missiles, the desired wounds would be obtained.

The controlling factors are size of the animal, orientation of the animal to the missiles, missile masses, missile velocities, translation of the animal, and yield of the nuclear device.

The size of the animal is a direct function of its age. Even on a strict maintenance diet, swine gain on the average $\frac{3}{4}$ pound per day. Animals were obtained which, on the scheduled date for Shot Priscilla, would weigh between 40 and 60 pounds. However, it was recognized and accepted that any prolonged delay would result in a significant

increase in the size of the animals, with an unavoidable decrease in the number of severe wounds. The heavier animals have a much greater thickness of hair, skin, and muscle and, hence, a greater resistance to missile injury. Because of the large number of animals involved, it was not feasible to shave the animals for Shot Priscilla.

The orientation of the animals with respect to the missiles was recognized as being of great importance; but again, because of the large numbers, it was not feasible to stake out each animal in optimum orientation. However, the exposure pens were divided by electrical fence into small segments, each to hold ten animals. This design was adopted as being simple, economical, and the only practical alternative to the problem of orientation. This design prevented mass huddling of the animals but provided for only random orientation within a given group of ten pigs. It was further necessary to provide an alarm system to effect ambulation of the animals immediately prior to the shot, because it was likely that the animals would, after being confined throughout the night, be lying on the ground in groups of ten, presenting the poorest possible target, unless previously aroused.

Satisfactory missile masses were obtained by selection of the size of the glass pane and the design of the window frame. This had been studied by previous experimentation.

The requisite missile velocities have already been mentioned. It was realized that lower velocities would be obtained from those observed for window panes in houses during previous operations, inasmuch as the venturi effect of the blast winds entering the orifice of a broken window would contribute to higher velocity missiles originating from a window pane in the side of a building. However, it was not economically feasible to design closed structures for such a large number of animals, and the design used was considered the next best.

Translation of the animal, if permitted, would result in a decrease in the effective velocity with which the missile would strike the animal and, consequently, a smaller number of significant wounds. For this reason, at the exposure stations where glass missiles were employed, the animals were placed in close apposition to the rear fence, in order to minimize animal translation.

The yield of the nuclear device is the greatest controlling factor of all. In the event of weapon failure or of a significantly lowered yield, a considerably reduced number of wounds would result.

Because of the many variables, a program of controlled wounds was planned whereby the surgeon was prepared to inflict the desired number of wounds on the operating table (Chapter 3).

B.4 EXPOSURE STATION DESIGN

Six exposure stations were designed for this project, with requirements as shown in Table B.1. Figure B.1 is a schematic drawing of Station 9. A similar design, except for dimensions, was used in Stations 6, 7, and 8. Figure B.2 is a schematic drawing of Station 10. Station 11 was identical in design to Station 10.

The outside fence was blastproof for the maximum specified peak overpressure. It was specified as No. 9 hog wire fence, with a 5-inch mesh. Inside the front fence of Stations 6, 7, 8, and 9 was placed an array of glass panes across the entire front of the pen. The array was two panes high, double-strength ordinary window glass, each pane measuring 20 by 32 inches, the long dimension parallel to the ground (Figure B.3). A 6-inch open space was provided between the lower margin of the window framing and the earth. Following the pilot study (Appendix A) this gap was closed across the entire front by double-strength window glass.

The rear 4-foot section of each pen was divided into 4- by 10-foot segments, each to contain ten animals, by three strands of electrical fence, 3, 7, and 11 inches from the earth. The blast-proof fence formed the rear boundary of each segment, to mimize animal translation. The distance from the glass array to the center of each pen depended on the peak overpressure to be encountered and was determined theoretically from velocity-distance-time curves. These distances were 20, 16.5, 13.0, and 10.0 feet for Stations 6, 7, 8, and 9, respectively. This distance represents the optimum distance to permit maximum acceleration of the missiles prior to collision with the target animal, at the same time being otherwise kept as small as possible to provide maximum missile density.

An alarm system to promote ambulation of the animals immediately prior to the shot was installed at Stations 6 through 9. It consisted of a set of automobile horns.

Stations 10 and 11 each contained 40 animals, and measured 20 by 10 feet, the long dimension parallel to the blast line. Prior to the shot, half of the animals were confined to the forward 10 feet by a single line of electrical force. No provision was made for establishing orientation or for insuring ambulation of the animals prior to the shot.

B.5 OPERATIONS

The animals were placed at 2400 hours on D−1, 6 hours 45 minutes prior to H-hour. Each animal number (ear tag) was recorded as the pig was placed, providing specific knowledge of the location of each animal prior to the shot. The alarm horns were activated at H−8 minutes.

Following the shot, the recovery began at H+15 minutes. Stations 11, 10, 9, 8, 7, and 6 were entered at H+30 minutes. Triage was carried out, and the seriously wounded were immediately evacuated to the hospital 7 miles to the north. Individual clinical records were initiated and maintained for each animal. This record describes all wounds incurred, missile tracts where found, missiles recovered from wounds, animal's location at time of shot, thermal and radiation doses received, therapeutic record, clinical course, and survival or sacrifice times as indicated.

Documentary photography was obtained at each exposure station prior to and after the shot. Where significant wounds were found, they were photographed before evacuation of the animal. Photography at the operating table and at autopsy was done where indicated. Whole-body diagnostic roentgenograms were obtained where indicated.

In addition, motion pictures at H-hour were obtained by GSAP cameras located at Stations 6 and 9. Because of the great length of the pen frontage, it was not feasible to create a stabilized area, and it was anticipated that dust obscuration would limit the value of the film. However, at a minimum, the general orientation and state of ambulation of the animals at Stations 6 and 9 could be determined from these films.

B.6 INSTRUMENTATION

A double Styrofoam trap was installed near the central portion of each pen. The functional area of the trap measured $11\frac{3}{8}$ by $35\frac{1}{4}$ inches, and the lower margin of the Styrofoam for the upper and lower traps was 17 inches and $1\frac{7}{8}$ inches from the earth, respectively. The distance from the front surface of the Styrofoam to the glass panes was $19\frac{1}{2}$, 16, $12\frac{1}{2}$, and $9\frac{1}{2}$ feet at Stations 6, 7, 8, and 9, respectively.

A thermal dosimetry line was provided by Project 8.2, consisting of both thermal radiant-energy meters and skin simulants at the front stake of each station. The range covered was from 2 to 135 cal/cm^2.

Radiation dosimetry was provided as outlined in Chapter 2.

Blast measurements, including peak overpressures and dynamic pressures, were obtained from DOD Project 1.1.

B.7 RESULTS

The missile mass-velocity results are presented for each station in Table B.2. This work was done by Program 33, Lovelace Foundation for Medical Education and Research, in conjunction with their own experiments during this shot.

Wound analysis is discussed in Chapter 7.

The blast, thermal, and radiation measurements are given in Table 7.1.

B.8 DISCUSSION

At shot time, the animal weights were found to be entirely according to the specifications which had been previously submitted. The distribution of animal weights was as follows: at Station 6, 40 to 55 pounds; Station 7, 50 to 70; Station 8, 25 to 60; and Station 9, 30 to 35.

The problem of orientation was essentially solved following modification of the electrical fence, which had previously proved mechanically unstable and had on pretest experiments failed to retain the pigs. An additional strand of electrified wire was added at a height of 7 inches from the earth and the mechanical stability of the electrical fence was increased by the use of guys secured to deadmen. In addition, the earth within the electrified segments was watered daily at 1700 hours for 3 days prior to the shot to ensure satisfactory grounding of the animals. As a result of these modifications, the segmentation by means of the electrified fence proved entirely adequate.

Because of the fact that, in the cold of the night, the animals had huddled, it was deemed essential that a means of both arousing and ambulating the animals be provided. To this end, a total of 12 automobile horns were installed and set for activation at H−8 minutes. On the first Priscilla cancellation, the animals were observed to have been aroused by the horns. Another consideration is the flash and the thermal effect with the resultant burn that occurs approximately $3\frac{1}{2}$ seconds prior to the arrival of the blast front. This it was believed would ensure ambulation of the already aroused animals. Postshot evidence of at least superficial lacerations of the extremities of nearly all the animals suggests success of the method. Motion pictures from GSAP cameras in steel towers at Stations 6 and 9 indicate that, although the animals were huddling at the instant of detonation, they were indeed aroused by the thermal pulse. It can be concluded, therefore, that the alarm horns were activated at such a long interval before the detonation that the animals became adjusted to the noise and resumed huddling, only to be successfully aroused by the thermal pulse.

The choice of size of glass pane and the closing of the 6-inch gap at the bottom of the glass array by additional double-strength window glass proved completely adequate with respect to providing an optimum size and distribution of glass fragments.

In view of the number of wounds observed and the apparently satisfactory size of the fragments, the missile velocities were evidently adequate and at least as high as the predicted values.

The general design of the animal inclosures in which the animals were placed immediately adjacent to the rear fence in order to prevent their translation was completely successful. There was some evidence of indentation of the rear hog-wire fence where

apparently some animals had been translated against it. However, at no place did destruction of the fence occur. Only a few of the animals showed evidence of a grid-type burn from contact with the 5-inch mesh hog-wire fence. It is estimated, on the basis of a rise of 5 degrees C per cal/cm^2 of incident thermal energy, that a sufficient rise in temperature of the hog-wire fence would occur such that a minimal burn would be inflicted on any animal in contact with the fence.

The yield of the nuclear device was essentially as predicted.

The gross appearance of the Styrofoam traps after the shot showed an essentially uniform distribution of fragments, a satisfactory percentage of which were of sufficient size to cause significant wounds. The traps for Shot Priscilla were not obstructed by animals, as in the case of Shot Wilson.

Several hundred superficial wounds from 0.5 to 5.0 cm in depth and from 1.0 to 10.0 cm in length were obtained. In addition, at least two penetrating wounds of the thorax and over 25 clinically recognizable penetrating abdominal wounds with extrusion of bowel were obtained. A significant number of penetrating wounds of the abdomen were demonstrated by roentgenographic examination with visualization of the foreign body; these were not diagnosed clinically.

The animals at Stations 10 and 11 incurred only minimal burns and presumably did not receive a lethal dose of radiation. All survived.

B.9 CONCLUSIONS AND RECOMMENDATIONS

The glass missiles produced an adequate number of superficial wounds, but probably only approximately 60 of the desired penetrating abdominal and thoracic wounds. With the random orientation, a maximum of only 60 percent of the animals were exposed to glass missiles; the results were, therefore, fully up to expectation. With optimum orientation, it is likely that all of the animals would have sustained severe wounds.

If in a future experiment random wounds are desired, it is recommended that the animals be staked out individually, as was done for Shot Wilson. This method of inflicting wounds would, then, be completely adequate.

TABLE B.1 EXPOSURE STATIONS

Station Number	Outside Dimensions	Maximum Peak Overpressure	Number of Animals	Glass Missiles
	ft	psi		
6	160 × 23.5	7.3	145	Yes
7	160 × 21.0	6.1	145	Yes
8	120 × 16.5	4.9	110	Yes
9	80 × 13.5	3.7	70	Yes
10	20 × 10.0	2.4	40	No
11	20 × 10.0	1.4	40	No

TABLE B.2 MISSILE ANALYSIS, SHOT PRISCILLA

	Station			
	6 (9032.06)	7 (9032.07)	8 (9032.08)	9 (9032.09)
Maximum peak overpressure, psi	7.3	6.1	4.9	3.7
Glass-trap distance, ft	19.5	16.0	12.5	9.5
Total number of missiles* †	112 194	170 390	123 158	81 68
Geometric mean velocity, ft/sec*	132.4	129	116	106
Geometric mean mass, grams*	0.43	0.48	0.61	1.07
Standard error of estimate*	0.066‡	0.086‡	0.074‡	0.109‡
Geometric mean velocity, ft/sec†	142	292	119	118
Geometric mean mass, grams†	0.34	0.29	0.59	0.96
Standard error of estimate†	0.072‡	0.082‡	0.086‡	0.080‡

* Bottom trap measurements $1\frac{7}{8}$ to $13\frac{1}{4}$ inches above earth.
† Top trap measurements 17 to $28\frac{3}{8}$ inches above earth.
‡ Log units.

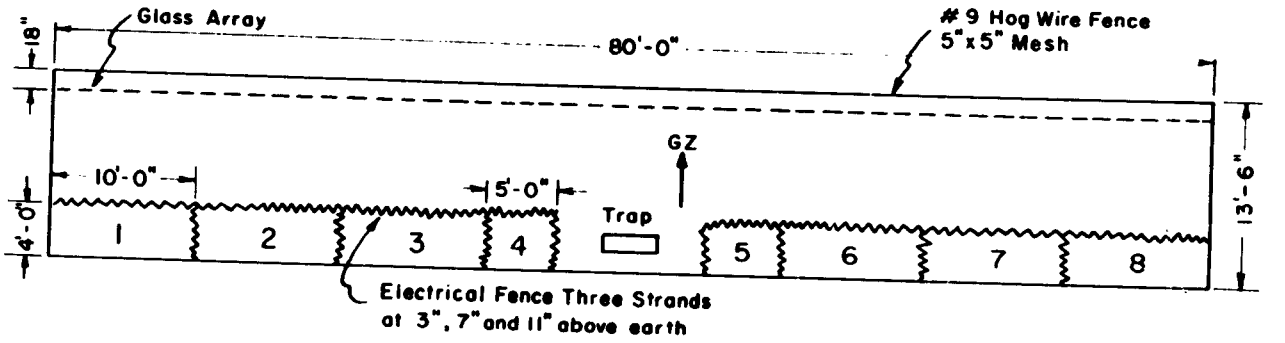


Figure B.1 Schematic drawing, Station 9.

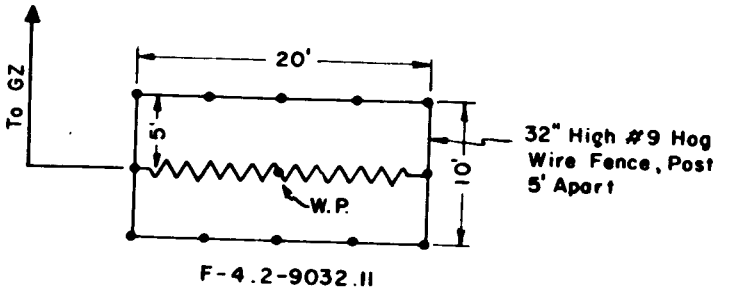
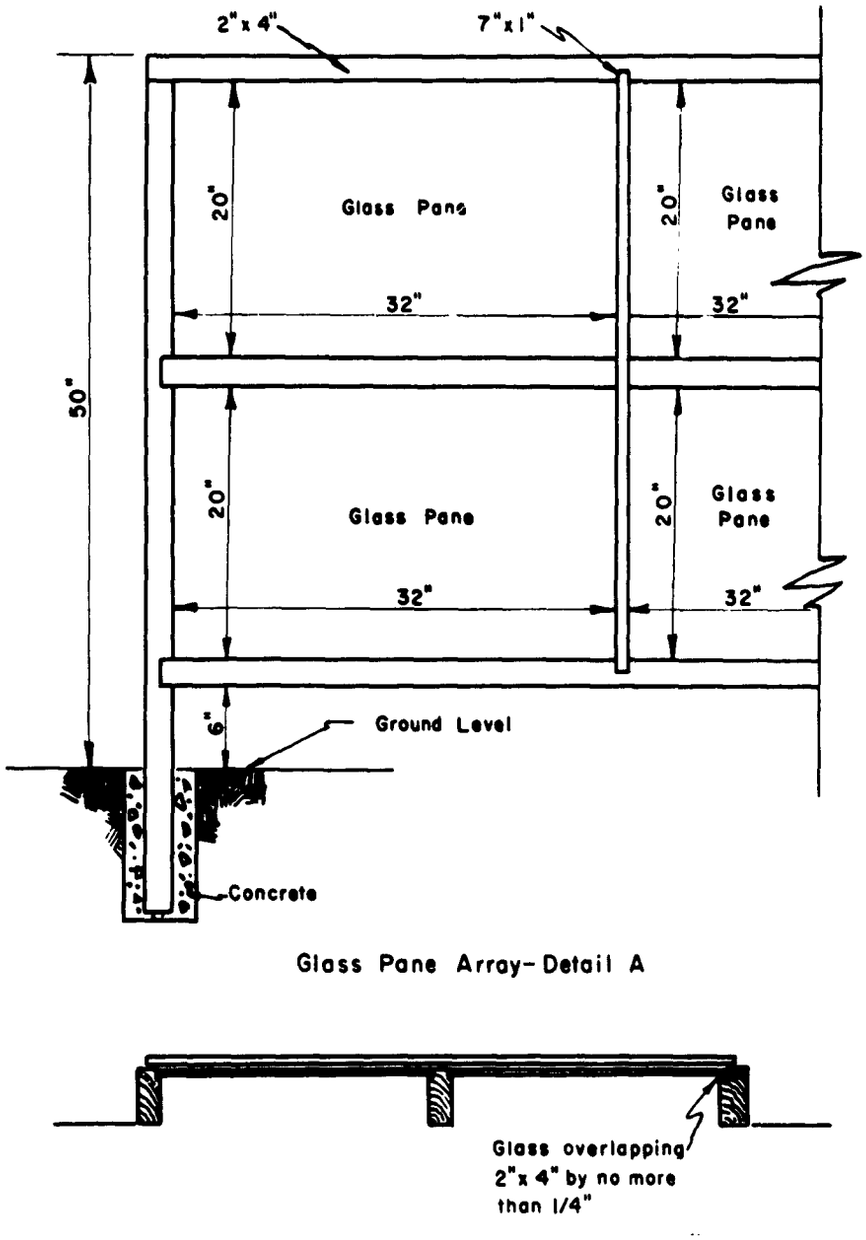


Figure B.2 Schematic drawing, Station 10.



Glass Pane Array- Detail A

Figure B.3 Schematic drawing of window-pane array.

Appendix C

DOSE PREDICTION AND STATION PLACEMENT FOR STUDIES OF LETHALITY FROM RADIATION

The information in this appendix is to be published in Reference 9. Related information is contained in References 37 through 40.

Lethality studies using experimental animals in the field are among the most difficult to perform. There are several difficulties inherent to the problem. These include the variations in physical parameters, the variations in biological parameters, and the rather severe restrictions imposed by the biological endpoint itself.

The physical dose equation for either neutrons or gamma rays is simply denoted as:

$$R = \frac{R_0 W e^{-D/\lambda}}{D^2}$$

Where: R = the total dose in rads

R_0 = the intercept value depending on the gadget design in rads-yd^2/kt

W = the yield in kt

λ = the mean free path in yards

D = the distance from point of detonation in yards

The physical parameters that may vary are R_0, W, and λ. Variations in any one or all of these will contribute to the error in R at any distance.

The biological response equation which represents the lethality information is:

$$Y = a + bX$$

Where: Y = the probit of percent mortality

X = the log of the dose in rads (or rem)

a = the intercept constant which depends on both the 50 percent lethal dose and the slope

b = the slope constant which is a function of the degree of heterogeneity of the population of animals involved

This equation as written does not influence the predicted doses from the physical equation. However, variations in a and b are important in the limited case, because, ideally, they should be placed on both sides of the LD_{50} value over fractional mortality regions only. It can be shown that fractional mortality only exists over the probit region from three to seven. Thus, the LD_{50} value is important, because a variation greater than ± 2 in the probit moves the animal out of the fractional death range, and in such regions the results have little weight. Also, because the rate of change of probit depends on b, an extremely large value of b (indicating a very homogeneous population) severely restricts the distance region over which fractional death occurs.

One other biological parameter is of direct importance in the dose equation if biological dose is predicted. This is the relative biological effectiveness (RBE) of the radiation under study. Rewriting the dose equation with RBE, the result is:

$$R_E = \frac{R_0 E W e^{-D/\lambda}}{D^2}$$

Where: R_E = dose in rem

E = the RBE in rem/rad

For situations in which mixed radiations, i.e., neutrons and gamma rays, are producing the effect, the above is preferable to the original physical dose equation for prediction and animal placement.

The error in R can be estimated by the evaluation of several partial derivatives in the following way:

$$R_E = \frac{R_0 E W e^{-D/\lambda}}{D^2}$$

$$\frac{\partial R_E}{\partial R_0} = \frac{E W e^{-D/\lambda}}{D^2}$$

$$\frac{\partial R_E}{\partial E} = \frac{R_0 W e^{-D/\lambda}}{D^2}$$

$$\frac{\partial R_E}{\partial W} = \frac{R_0 E e^{-D/\lambda}}{D^2}$$

$$\frac{\partial R_E}{\partial \lambda} = \frac{R_0 E W e^{-D/\lambda}}{\lambda^2 D}$$

The total error in R_E, ΔR_E, is then evaluated by squaring and grouping the above equations:

$$(\Delta R_E)^2 = \left(\frac{EWe^{-D/\lambda}}{D^2}\Delta R_0\right)^2 + \left(\frac{R_0 W e^{-D/\lambda}}{D^2}\Delta E\right)^2 + \left(\frac{R_0 E e^{-D/\lambda}}{D^2}\Delta W\right)^2 + \left(\frac{R_0 EWe^{-D/\lambda}}{\lambda^2 D}\Delta\lambda\right)^2$$

$$\pm\Delta R_E = \frac{e^{-D/\lambda}}{D^2}\sqrt{(EW\Delta R_0)^2 + (R_0 W\Delta E)^2 + (R_0 E\Delta W)^2 + \left(\frac{R_0 EWD\Delta\lambda}{\lambda^2}\right)^2}$$

and, the fractional error in R_E is:

$$\frac{\Delta R_E}{R_E} = \sqrt{\frac{(EW\Delta R_0)^2 + (R_0 W\Delta E)^2 + (R_0 E\Delta W)^2 + \left(\frac{R_0 EWD\Delta\lambda}{\lambda^2}\right)^2}{R_0 EW}}$$

or:

$$\frac{\Delta R_E}{R_E} = \sqrt{\left(\frac{\Delta R_0}{R_0}\right)^2 + \left(\frac{\Delta E}{E}\right)^2 + \left(\frac{\Delta W}{W}\right)^2 + \left(\frac{D\Delta\lambda}{\lambda^2}\right)^2}$$

which for any particular set of conditions reduces to:

$$\frac{\Delta R_E}{R_E} = \sqrt{K_1 + K_2 D^2}$$

and is a varying function with D the fractional error in R_E becoming larger as D increases.

In cases in which physical dose is being estimated or in which gamma ray dose (using a defined RBE = 1) is being estimated, the partial derivative with respect to E vanishes.

In the mixed radiation case in which the basic dose formula is:

$$R = \frac{R_{0\gamma} W e^{-D/\lambda_\gamma}}{D^2} + \frac{R_{0n} E W e^{-D/\lambda_n}}{D^2}$$

the error formula becomes:

$$\pm\Delta R = \frac{1}{D^2} \left\{ \left[\left(EW\Delta R_{0m} \right)^2 + \left(R_{0m} W \Delta E \right)^2 + \left(\frac{R_{0n} EWD\Delta\lambda_n}{\lambda_{n^2}} \right)^2 + \left(R_{0n} E \Delta W \right)^2 \right] \left[e^{-D/\lambda} \right]^2 + \left[(W\Delta R_{0\gamma})^2 + \left(\frac{R_{0\gamma} WD\Delta\lambda_\gamma}{\lambda_{\gamma 2}} \right)^2 + (R_{0\gamma}\Delta W)^2 \right] \left[e^{-D/\lambda\gamma} \right]^2 + 2R_{0n} R_\gamma E \Delta W^2 \left(e^{-D/\lambda_{ne} - D/\lambda_\gamma} \right) \right\}^{1/2}$$

and the fractional error can be evaluated as previously.

The error in the predicted probit may be determined similarly, if,

$$Y = a + bX = a + b \log_e R$$

then,

$$\pm\Delta Y = \sqrt{\Delta a^2 + (\log_e R \Delta b)^2 + \left(\frac{b\Delta R}{R} \right)^2}$$

Even though $\Delta R/R$ is a function of distance, it is essentially constant over the distance range involving lethality studies. Thus, the error in probit over the range of interest is:

$$\pm\Delta Y = \sqrt{C_1 + C_2 (\log_e R)^2}$$

This shows that the probit error increases as the dose increases, but the change is small over narrow dose ranges. Also, because the physical dose error was shown to be directly proportional to distance, the variations tend to cancel each other, and the fractional probit error remains about the same over the restricted lethality range.

It was mentioned that the heterogeneity of the population used was important in prediction and placement. On examination, it is found that the probit slope b and the radiation mean free path λ are closely related, and over a restricted range, the probit change per unit distance is essentially constant. Thus, for neutrons, the probit change per yard is greater than for gammas (which have a larger λ). Because probit changes of 0.5 units occur over distances of 15 to 25 yards, depending on the population spread and the mean

free path, and because the physical and biological errors cause probit errors as great as ±1 unit, it is apparent that under the usual limiting conditions the placement spread must be larger than the 0.5 unit probit, and stations must be added to allow for error at both ends. Also, the experimenter must be willing to accept loss of data from both zero and 100 percent mortality stations, in order to be certain that enough fractional mortality points are available for analysis.

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